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To cite this version:

Karine Constant, Marion Davin, Gilles de Truchis, Benjamin Keddad. The European renewable energy sector in calm and turmoil periods: The key role of sovereign risk. 2023. hal-04346858

HAL Id: hal-04346858
https://hal.inrae.fr/hal-04346858v1

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CEE-M Working Paper 2023-13

The European renewable energy sector in calm and turmoil periods: The key role of sovereign risk

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Abstract

This paper explores the comparative role of sovereign default risk and several high-frequency macrofinancial indicators that may explain the drop in European renewable energy stocks observed during the 2008 financial crisis and the European debt crisis. We use a two-state time-varying transition probability Markov-switching model to investigate how they impact the bull and bear market trends of renewable stocks. Our main finding is that public financing conditions, captured by sovereign default risks, play a key role in both market regimes, while the other variables affect the renewable energy stocks only in calm or turmoil periods. Moreover, sovereign risk is identified as the main determinant of the European renewable energy stock dynamics in both regimes in the period under review. Finally, we suggest that this effect may be due to the sensitivity of investors to the energy policy uncertainty, entailed by such a pressure on public finances.

Keywords: Renewable energy, Stock prices, Financial crisis, European debt crisis, Markov-switching model
JEL: G10, Q43, Q42

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1. Introduction

All economic activity requires energy. Currently, this energy is mostly obtained from the use of fossil fuels. However, these sources of energy have a negative environmental impact that is far from negligible. A striking example is the global climate change that we are already experiencing and whose damages will greatly worsen if the world greenhouse gas emissions stay on the same path (IPCC 2022a). In this context, a transition to Renewable Energy (hereafter, RE) is broadly identified as necessary, being one of the main instruments of climate change mitigation.[1] The EU 2030 climate and energy framework supports this view. In October 2023, the revised Renewable Energy Directive EU/2023/2413 recalls that "RE plays a fundamental role in achieving [the Union's greenhouse gas emissions reduction target], given that the energy sector currently contributes over 75% of total greenhouse gas emissions in the Union". This directive has even raised the overall EU's RE target for 2030 from 32% to 42.5% of the energy mix, while the RE share of EU energy consumption was only 21.8% in 2021.[2]

To meet this challenge, it is crucial to gain a better understanding of the factors that trigger investments in renewables. In this regard, Sadorsky (2012) highlighted that "very little is known about the relationship between clean energy stock prices and various other important macroeconomic variables", which remains an issue a decade later. A simple way to do this is to investigate the determinants of RE stock prices. This is what this paper seeks to do by focusing on the European Renewable Energy stock index (ERIX), which includes the largest European companies in the areas of RE, such as wind, marine, solar, geothermal, biomass, and water energy.

Among the potential determinants, our hypothesis is that pressure on public debt should be particularly important. This is what this paper is going to test. Indeed, while private finance is needed for a low-carbon energy transition in Europe, public author-

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[1] We use the terms "renewable energy" and "clean energy" interchangeably in the paper, as RE are relatively clean with respect to fossil fuels.

[2] Data from the European Commission (https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-targets_en).

ities play a central role promoting such investments through policies (as recalled in e.g. European Commission 2017, IRENA 2018).[3] Public authorities typically implement incentive-based policies to support the attractiveness of RE investments and hence leverage private investment. It has been shown that such policies and, in particular, feed-in tariffs — guaranteeing a minimum price for RE producers — can foster private investment flows (see, e.g., Bürer and Wüstenhagen 2009, Ritzenhofen and Spinler 2016, Ang et al. 2017).[4] However, the efficiency of these policies depends also on their consistency (see, e.g., Dijkgraaf et al. 2018), while European governments' budgets have been under pressure recently because of the global financial crisis of 2008 and the European debt crisis.

The evolution of ERIX since 2008 shows the peculiarity of this market and the close connection with public financing conditions. As illustrated in Figure 1, the financial markets in Europe - represented by a major barometer of the stock market performance (the Euro Stoxx 50 index, i.e. ESX) - were particularly shaken by the global financial crisis of 2008 and the European sovereign debt crisis. Like other markets, ERIX fell after the 2008 crisis. However, while the others rebounded starting from the end of 2009, RE stock prices continued to fall until after the European debt crisis, reaching their lowest level in late 2012. At the end of the period analyzed, RE stock prices were still far from their level in 2008.[5] This suggests that investors' behavior as regards the clean energy stock market may have been different following the 2008 crisis. Moreover, Figure 1 strikingly highlights the opposing trends between ERIX and the European sovereign credit default swap index (thereafter SOVX) during two distinct phases. In the first phase, from 2008 to 2012, the increase in SOVX is associated with the drop in ERIX. During this period, SOVX sharply increased in almost all EU countries, and public financing conditions

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[3] European Commission (2017) reports that "more than 1300 support measures (economic, financial, regulatory, administrative, support) for the development of renewables were in place in the EU countries" between 2005 and 2015.

[4] See Polzin et al. (2015) who provide an interesting comparison of the effects of different support mechanisms for RE.

[5] RE stocks price was around 330 on 27 December 27, 2019, compared to 567 on January 4, 2008. See https://sgi.sgmarkets.com/en/index-details/TICKER:ERIX/performances/.

deteriorated quickly, which led governments to reduce public spending and budget deficit. The literature shows that it implied a decline in policy support for RE (FS-UNEP 2012; 2014) and implicitly in the popularity of energy policies among European investors (Hofman and Huisman 2012). The second phase takes place from 2012 to the end of the sampling period and depicts the opposite dynamic with a continuous decrease in SOVX corresponding to a period of sustainable RE stocks recovery. Therefore, one potential explanation for the dynamics of RE could be the particular role of public debt pressure.

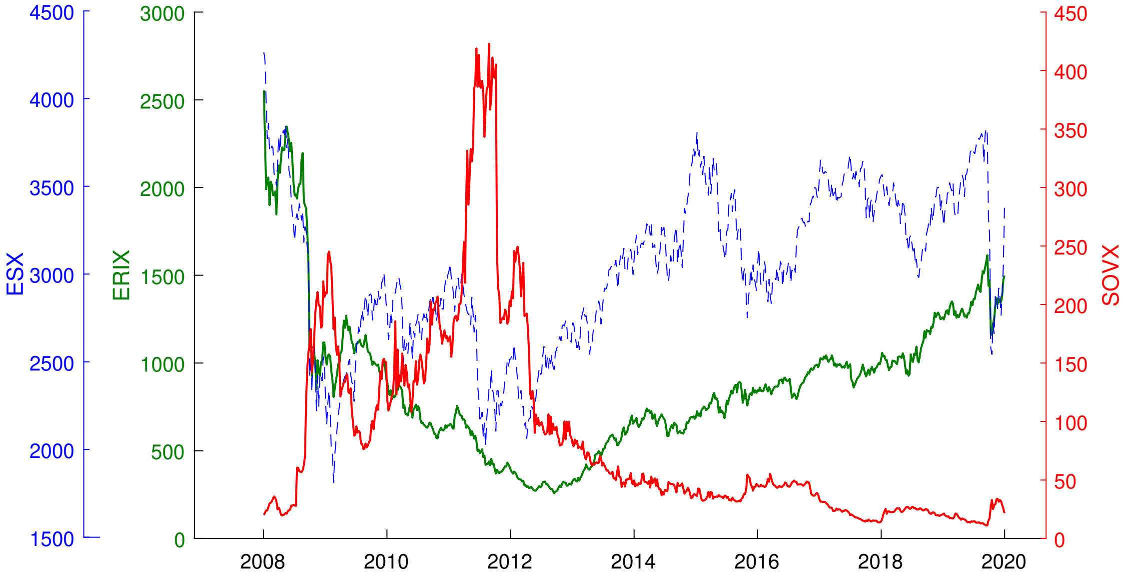

Figure 1: The evolution of the European renewable energy stock index (ERIX), the iTraxx sovereign credit default swap index (SOVX) and the Euro Stoxx 50 index (ESX) between 2008 and 2019.

To examine the specific effect of sovereign risk on RE stocks, we proceed in two steps. First, through a robust sequential approach, we compare sovereign risk with other relevant macrofinancial indicators, corresponding to specific markets that have been identified in the literature as closely linked to RE, along with broader key variables of the private sphere. Typically, the prices of fossil fuels and carbon allowance are intuitively regarded as potential determinants of investment in RE, as they are in direct competition with renewables and may hence affect their attractiveness (see e.g. Egenhofer et al. 2011, Reboredo 2015, Reboredo et al. 2017, Degiannakis et al. 2018, Teixidó et al. 2019).

Another important potential determinant of the RE sector performance identified in the literature is the high-technology sector (see e.g. Henriques and Sadorsky 2008, Sadorsky 2012, Managi and Okimoto 2013, Reboredo 2015), because its innovations may enhance the efficiency of RE and reduce the associated capital cost and because both sectors rely on similar resources/labor force (see e.g. Kyritsis and Serletis 2019, Inchauspe et al. 2015). We also take into account the potential role of the main stock index of the Eurozone (i.e., Euro Stoxx 50), as it acts as a benchmark to gauge the performance of leading companies in Europe. Since the success of RE relies on active participation from the private sector[6], we also consider the potential role of the banking sector, represented by the European bank credit risk.

In the second stage of our analysis, we investigate how the interplay between sovereign risk and European policy uncertainty, related to energy and regulation, may affect RE stocks, assuming that higher sovereign stress may change the perception of public support for RE.

To conduct this analysis, we adopt a two-state Markov-switching model, which is a powerful tool to endogenously capture changes in market trends. This allows us to study whether and how the determinants of the European RE stock prices may change according to market conditions, namely calm *versus* turbulent periods. More importantly, we consider time-varying transition probabilities to examine how the selected macrofinancial variables influence the probability of RE stock market being bull or bear, which correspond to calm and turbulent periods, respectively. For that, our sampling period extends from 2008 to 2019 to take into account the two main turbulent periods during which sovereign risk was particularly high (i.e., the subprime crisis and the European debt crisis), but also periods of calm, mainly after 2012, when sovereign risk fell sharply.

Our analysis reveals that the variables affecting the dynamics of the RE stock prices vary according to market conditions. On the contrary to all the other variables consid-

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[6] The vast majority of renewable energy investment is indeed private — over 90% in 2016 — according to the International Renewable Energy Agency (IRENA 2018).

ered, sovereign risk plays a significant role for RE in both calm and turbulent periods. More precisely, the probability of staying in or switching to the calm regime is higher when sovereign credit risks are decreasing. Moreover, through a forecasting and comparative analysis of the macrofinancial factors we examine, we emphasize that the stress on public debt is the main driver of RE stock price movements in both calm and turbulent regimes.

Finally, we provide explanations of such a key role of sovereign risk in RE performances. For this, we rely on the existing literature and a complementary analysis of the link between SOVX, energy policy uncertainty, and regulation uncertainty at the European level. Although shifts in energy policies can stem from various factors, substantial pressure on public finances is likely to affect support for renewable energy policy, as observed during the two crises (FS-UNEP 2012; 2014). Moreover, it has been shown by Azqueta-Gavaldón et al. (2023) that the sovereign debt crisis in Europe was closely accompanied by a rise in policy uncertainty. Such a phenomenon may, then, alter the perception of the risk-return ratio of RE investments (see, e.g., Hofman and Huisman 2012, Wüstenhagen and Menichetti 2012, Ritzenhofen and Spinler 2016, Ang et al. 2017). More broadly, we find that pressure on public finance is associated with uncertainty on the public support for RE, and this may explain why sovereign risk slowed the recovery of the renewables sector during the crisis..

The rest of the paper is laid out as follows. In Section 2, we detail our data set. In Section 3, we present our empirical strategy, particularly the Markov-switching model adopted in this paper. In Section 4, we discuss our empirical results. Section 5 concludes.

2. Data

In this paper, we focus on RE stock prices, whose evolution gives information about the profitability of RE companies and hence allows to appreciate the dynamics of the RE sector. More precisely, to proxy the European clean energy sector, we use the European Renewable Energy Stock Index (ERIX). It consists of the 10 largest European companies that are active in either one or several investments in biofuels, geothermal, marine, solar, water, and wind.[7]

To examine the effects of sovereign risks and of the macrofinancial environment on this RE stock index, we consider six information variables. As our variable of interest is sampled weekly, we have chosen to focus on macrofinancial variables sampled at the same frequency.

First, we include the iTraxx European SOVX index, representing an equally weighted average of the sovereign credit default swap (CDS) spreads maturing at 5 years. [8] We have chosen this maturity because it has the highest liquidity, making it the best to capture information about CDS. This index reflects both market sentiment on European sovereign risk and market pressure on the sovereign debts of European governments. When this index increases, the cost of insuring sovereign debt against default goes up and exacerbates the difficulties encountered by governments in raising funds. Higher sovereign CDS may thus reduce investors' expectations of governmental support for RE and hamper the performance of the clean energy sector.

Second, we consider variables representing the potential trade-off between fossil fuels and RE. We will examine whether a change in oil prices, and more precisely the spot Brent crude oil price (BRENT), affects the performance of the RE stock returns.[9],[10] Moreover, we take into account carbon prices as the main difference between fossil fuels and RE is their carbon content. For that, we consider the European Carbon Index (CARBIX) calculated as an exchange-based price for the current market value for emission allowances in the EU Emissions Trading Scheme (EU ETS).[11]

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[7] ERIX is computed by the Société Générale (`https://www.sgindex.com`). Note that the stocks included in the index change over time and ERIX is created by applying calculations to determine the weighting of each company.

[8] Data for BANX and SOVX are obtained from Thomson Reuters Datastream.

[9] Oil price data were obtained from Datastream (`http://www.eia.doe.gov`).

[10] We could also consider variables capturing the price of gas and in electricity on the European market. However, these prices are relatively stable over the period analyzed and we have found that they do not play a significant role in the renewable market. Results are available upon request.

[11] Data for CARBIX are extracted from Thomson Reuter Datastream. Additional information can be found at `https://www.eex.com/en/markets/trading-ressources/indices`

Third, the RE sector performance depends on advances in technology, especially those related to transportation and storage capacity. That is why we consider as an information variable the Europe 600 Technology Stoxx index (ETX), which covers the largest companies in the technology sector.[12] This allows us to examine whether the stock market performance of high-technology companies affects investment decisions in clean energy stocks.

Fourth, to capture the general state of the financial market, we use the major barometer of stock market performance in Europe, i.e. the Euro Stoxx 50 index (ESX), covering the 50 leading companies from 12 major Eurozone countries.

Fifth, we consider bank credit default risk, as banks represent a significant source of funding for the clean energy sector. Accordingly, we include the ITraxx Europe Senior financial index (BANX), composed of 5-years equally weighted credit default swaps of twenty-five major financial entities (senior debt). Through this analysis, we aim to capture the impact of significant stress in the banking sector on clean energy companies.

The data set is synchronized weekly and runs from January 4, 2008, to December 27, 2019, for a total of $n = 625$ observations. Our sample therefore covers the last two financial crises. Although daily data are available, we argue that a weekly frequency is more appropriate to capture the transmission of macrofinancial shocks. Moreover, we favor weekly data to avoid too frequent and irrelevant switches in regime probabilities that would lead to misidentification of market regimes and to prevent higher frequency noise that tends to obscure the structure in the conditional mean (see e.g. Maheu et al. 2012). All variables are transformed to obtain standardized log-returns and facilitate the estimations and the analysis of the results. Indeed, as we essentially consider macro-financial standardized log-returns, the resulting variables under analysis are roughly standard Gaussian and hence put on a comparable scale.

Table 1 displays the Pearson (above diagonal) and Spearman (below diagonal) correlations between all information variables. It shows that correlations are moderately

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[12] The data on all components of Stoxx indices and associated details are available on the Stoxx website (`http://www.stoxx.com`).

low between SOVX and all others variables. This also holds for CARBIX and BRENT. In contrast, correlations are moderately high between BANX, ETX, and ESX, meaning that the information they are likely to reflect when explaining the nonlinear dynamics of ERIX is to some extent similar. However, their correlation coefficients are far from unity and their impacts could be different.

Table 1: Pearson and Spearman correlations between all information variables

ρ_S / ρ_P	BANX	BRENT	CARBIX	ESX	ETX	SOVX
BANX	1.000	-0.179	-0.088	-0.634	-0.510	0.219
BRENT	-0.149	1.000	0.055	0.344	0.310	-0.018
CARBIX	-0.111	0.080	1.000	0.089	0.080	-0.057
ESX	-0.686	0.266	0.082	1.000	0.823	-0.139
ETX	-0.542	0.259	0.045	0.789	1.000	-0.139
SOVX	0.313	-0.010	-0.067	-0.209	-0.152	1.000

Notes: The figures below the diagonal are Spearman (ρ_S) correlations. The figures above the diagonal are Pearson (ρ_P) correlations

3. The empirical strategy

3.1. The empirical model

Our empirical approach is based on the so-called Markov-switching model of Hamilton (1989; 1990). This type of model assumes that the variable of interest is driven by state-dependent dynamics in a probabilistic environment represented by a Markov chain. Although Hamilton's original model is powerful, it is unable to provide information on the underlying factors driving the Markov chain. This issue has been addressed by Filardo (1994), Filardo and Gordon (1998), and Kim et al. (2008), among others, who extend the basic Markov-switching model to account for time-varying transition probabilities (TVTP). The idea is that the probabilities of switching from one state to another are likely to vary over time according to the influence of an information variable.

Markov-switching models are often used in the financial literature as they are able to capture the underlying market state (see, e.g., Maheu and McCurdy 2000, Dufrénot et al. 2011, Maheu et al. 2012). Concerning more specifically the renewable energy sector, Managi and Okimoto (2013) apply a two-state Markov-switching vector autoregressive model to examine the relationships among oil prices, the clean energy sector, and the technology sector. In contrast, we use a TVTP Markov-switching (TVTP-MS) model to investigate more broadly whether the macrofinancial environment can help to explain the state-dependent dynamics of the ERIX returns.

We adopt a two-state specification that allows us to identify the trends of the renewable energy market. Typically, the model endogenously identifies the underlying positive (bull) and negative (bear) market conditions, traditionally associated to calm and turbulent regimes. More specifically, we assume that the state-dependent dynamics of the ERIX standardized log-returns, r_t, is given by

$$r_t = \mu_{s_t} + \sigma^2_{s_t}\varepsilon_t, \qquad s_t = \{1,2\}, \qquad t = 1,\ldots,n \tag{1}$$

where s_t is an ergodic Markov-chain. In the rest of the paper, $s_t = 1$ and $s_t = 2$ will refer to the calm and turmoil regime, respectively. The parameter μ_{s_t} is the mean of the standardized ERIX log returns in the regime s_t. It is therefore expected to be positive in regime one and negative two. We also expect the regime-dependent variance parameter, $\sigma^2_{s_t}$, to be higher in the turmoil regime. As in Maheu et al. (2012), we rely on a Gaussian distributional assumption for ε_t.[13]

The benchmark model is the fixed transition probability (FTP) one, whose transition matrix structure is

$$P = \begin{pmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{pmatrix}. \tag{2}$$

The conditional probabilities p_{ij} of moving from state j to state i are given by[14]

$$p_{ij} = \mathbb{P}(s_t = i | s_{t-1} = j) = \frac{\exp(\alpha_{ij})}{1+\exp(\alpha_{ij})}, \qquad \forall i,j \in \{1,2\}. \tag{3}$$

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[13] We have tested for the presence of p lags of r_t in the model and the preferred specification is always the one with $p = 0$. This finding is consistent with the financial literature.

[14] For instance, p_{21} indicates the probability of switching from regime 1 to regime 2, while p_{11} indicates the probability of staying in regime 1.

We prefer the more flexible TVTP specification in which the macrofinancial environment may influence the transition probabilities through the following logistic function

$$p_{ij}(z_t) = \mathbb{P}(s_t = i | s_{t-1} = j, \mathcal{F}_{t-1}) = \frac{\exp\left(\alpha_{ij} + \gamma_{ij} z_{t-l}\right)}{1 + \exp\left(\alpha_{ij} + \gamma_{ij} z_{t-l}\right)}, \qquad \forall i, j \in \{1, 2\}. \tag{4}$$

$\mathcal{F}_{t-1}$ represents the information set available in $t-1$ and reflects the time-varying nature of the conditional regime-switching probabilities. The variable z_t represents the standardized log-returns of a macrofinancial variable and $l \geq 1$ the lag of that variable chosen according to AIC criteria. Notice that we have to estimate only $p_{11}(z_t)$ and $p_{22}(z_t)$ as the two other probabilities are simply given by $p_{21}(z_t) = 1 - p_{11}(z_t)$ and $p_{12}(z_t) = 1 - p_{22}(z_t)$. Indeed, from one period to another, the dependent variable can either switch to the other regime or remain in the current regime. γ_{ij} makes explicit the link between the standardized log-returns of the ERIX index and the macrofinancial variable z_{t-l}. Typically, if the magnitude of γ_{ij} is large (resp. small), even a tiny (resp. large) variation of the information variable will strongly (resp. weakly) impact the probability of switching from state j to state i. In contrast, α_{ij} captures the time-independent unobserved factors that impact p_{ij}. For instance, consider $p_{ii}(z_t)$, the probability of staying in regime i. As the ergodic assumption implies that each regime is persistent, we expect $p_{ii}(z_t)$ to be relatively close to 1 even when $z_{t-l} = 0$. This reveals that α_{ii} drives the persistence of the Markov chain and reflects the prominent role of the time-independent factors. Reversely, the information variable can only locally influence p_{ij}. By convention, the literature considers that if the probability of being in a given regime goes beyond 1/2, we enter that regime.

3.2. *Estimation*

To estimate the TVTP-MS model, we apply the maximum likelihood estimator of Filardo (1994), as Li and Liu (2020) has recently demonstrated its asymptotic normality.

The log-likelihood function is defined as

$$L(r_t;\Theta) = \sum_{t=1}^{n}\sum_{i=1}^{2}\sum_{j=1}^{2}\ln\left(f(r_t|s_t=i,s_{t-1}=j,\mathcal{F}_{t-1},\xi_{t-1};\Theta)\times\mathbb{P}\left(s_t=i,s_{t-1}=j|\Theta_t,\xi_{t-1};\Theta\right)\right)$$

$$= \sum_{t=1}^{n}\ln f(r_t|\mathcal{F}_{t-1},\xi_{t-1};\Theta), \tag{5}$$

where the unconditional density function (with respect to the Markov-chain) depends on $\xi_{t-1} = (r_{t-1}, r_{t-2}, \ldots, r_1)$, the vector of historical values of the endogenous variable and $\mathcal{F}_{t-1} = (z_{t-1}, z_{t-2}, \ldots, z_1)$, that of the information variable up to $t-1$. Under the normality assumption, the conditional density is defined as

$$f(r_t|\mathcal{F}_{t-1},\xi_{t-1};\Theta) = \frac{1}{\sqrt{2\pi\sigma_{s_t}^2}}\exp\left(\frac{-\left(r_t-\mu_{s_t}\right)^2}{2\sigma_{s_t}^2}\right). \tag{6}$$

In practice, Markov-switching models are subject to numerical instabilities due to the existence of local maxima that make difficult the search for the global optimum. As the number of local maxima is directly linked to the complexity of the likelihood function, estimating the model when all information variables enter the logistic function is delicate. For this reason, we prefer to analyze each information variable one by one.[15] This raises the question of goodness-of-fit evaluation and model comparison. Unfortunately, it is well-known that the so-called likelihood ratio (LR) test has some issues regarding its asymptotic distribution in the presence of Markov-switching models (see Qu and Zhuo 2021). To circumvent this issue, we use a valid block bootstrap procedure under the null hypothesis that the model has fixed transition probabilities. The bootstrapped critical values at 10%, 5%, and 1% are 7.1663, 9.4967, and 13.1787, respectively. Additionally, we consider various diagnostic tools that help to compare the impact of each information variable across the models. They are detailed in the next subsection.

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[15] Notice that we investigate the forecasting performance of a multi-information variables model in Section 4.2.2.

3.3. *Diagnostic tools*

To facilitate the analysis of the results, we rely on various diagnostic tools. First of all, we check whether the TVTP-MS specification outperforms the fixed transition probability Markov-switching (FTP-MS) model by carrying out a likelihood ratio (LR) test for each macrofinancial variable. Furthermore, we compute two indicators to quantify the impact of these information variables on transition probabilities (see Aloy et al. 2014).

The first indicator is the threshold value of z_{t-l} at the inflection point of the logistic function in Eq. (4), labeled ZM, which corresponds to a transition probability of 0.5. Beyond this value of z_{t-l} the transition probability becomes higher or lower than 0.5. The threshold value is given by

$$ZM_{ij} = -\frac{\alpha_{ij}}{\gamma_{ij}}, \qquad \forall i, j \in \{1, 2\}. \tag{7}$$

The second is the maximum marginal probability (MMP), which corresponds to the slope of the tangent at ZM. This gives the maximal variation of p_{ij} following a 1% increase in the value of the information variable z_{t-l} at the inflection point. This maximal variation is given by

$$MMP_{ij} = \frac{\gamma_{ij}}{4}, \qquad \forall i, j \in \{1, 2\}. \tag{8}$$

Finally, to assess the ability of each information variable to explain the dynamics of the transition probabilities, we rely on variable standardization and the limit theory of Li and Liu (2020) to perform comparisons between γ_{ij} coefficients. More specifically, as all log-return information variables are standardized and hence roughly standard Gaussian[16], they are unitless and the estimated coefficients are easier to compare. Besides, the asymptotic normality, demonstrated by Li and Liu (2020), ensures that we can perform z-tests to formally test for $H_0 : \widehat{\gamma}_{ij}^{(a)} = \widehat{\gamma}_{ij}^{(b)}$, where $\widehat{\gamma}_{ij}^{(a)}$ is obtained for a particular

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[16] It is widely documented in the financial literature that log-returns are in general Gaussian.

information variable, a, and $\widehat{\gamma}_{ij}^{(b)}$ for another one, b.[17]

4. Empirical results

4.1. The impact of macrofinancial variables on RE dynamics

As a preliminary step, we consider the FTP-MS model. The analysis of this benchmark model allows us to characterize the dynamics of the RE stocks without explicitly relying on specific macrofinancial variables. The computation of information criteria reveals that the most suitable model does not include any lags of the dependent variable. The state-dependent dynamics of the ERIX index is illustrated in Figure 2, with the corresponding regime probabilities (Figure 2c). It clearly exhibits alternating episodes of calm (in blue) and turbulent (in red) periods (visible in terms of returns in Figure 2b) that correspond to bull market episodes and downward trends in ERIX index, respectively (Figure 2a).[18] The estimation results are presented in Table 2 and reveal, as expected, that the first regime is characterized by a positive constant coefficient ($\mu_1 > 0$) and a low variance ($\sigma_1 < 1$), whereas the second regime exhibits a strongly negative constant-coefficient and is riskier ($\sigma_2 > \sigma_1$).

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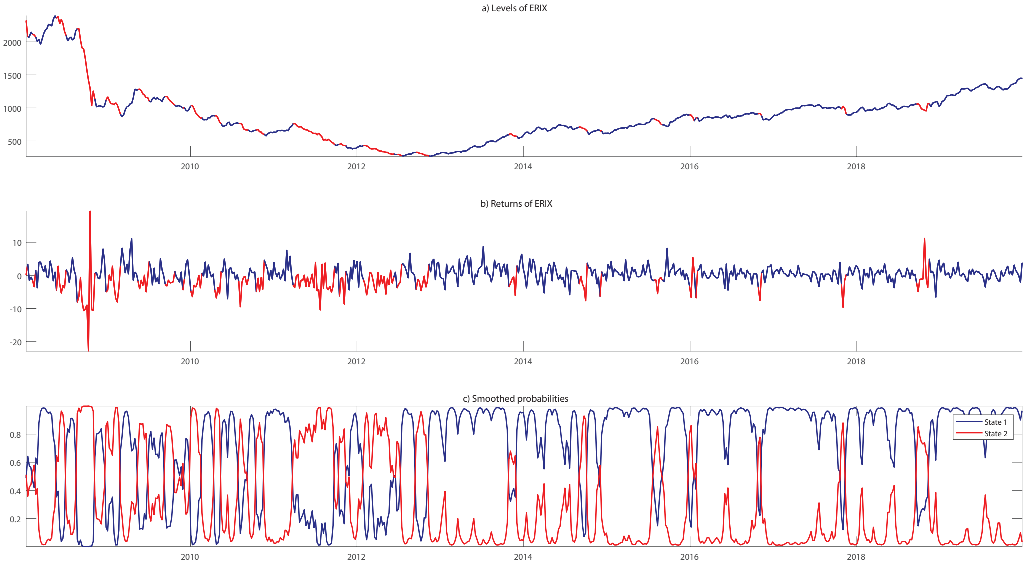
[17] Notice that in the rest of the paper, for the sake of simplicity, we sometimes use by abuse of notation the word "returns" instead of "standardized log-returns".

[18] The plot has been obtained under Student's t distribution, which slightly improves the likelihood compared to the Gaussian one. Nevertheless, the results in Table 2 are obtained under the normality assumption to preserve the comparability with the Gaussian TVTP-MS model discussed above.

Figure 2: Description of the ERIX in the two regimes



Notes: Calm regime (State 1) is represented in blue and turbulent regime (State 2) is represented in red.

Although the FTP-MS model is parsimonious, it assumes fixed transition probabilities over the whole period and is unable to capture changes that could be induced by some particular macrofinancial variables. Therefore, we consider a TVTP-MS model to investigate if and how the transition probabilities may be influenced by specific variables. More precisely, we examine the impact of each of the six macrofinancial factors described previously on the RE stock prices. Anticipating the results, we find that the TVTP-MS model is always more suitable than the FTP-MS model to explain the nonlinear dynamics of the ERIX index returns (see LR tests in Table 2). We also observe that SOVX is the model with the lowest AIC criteria and the highest LR statistic.

Table 2: FTP and TVTP Markov-switching estimates with the European Renewable Energy stock index (ERIX) as the endogenous variable

	FTP	CARBIX	BRENT	ETX	ESX	BANX	SOVX
Regime 1							
μ_1	0.058*	0.065*	0.099***	0.054	0.058*	0.05	0.064**
	(-0.033)	(-0.035)	(-0.033)	(-0.033)	(-0.035)	(-0.031)	(-0.032)
σ_1	0.741***	0.745***	0.705***	0.71***	0.724***	0.734***	0.736***
	(-0.094)	(-0.086)	(-0.095)	(-0.091)	(-0.083)	(-0.078)	(-0.079)
α_{11}	4.79***	4.966***	4.54***	6.266***	5.266***	5.38***	11.534**
	(-0.609)	(-0.66)	(-0.87)	(-1.859)	(-0.914)	(-0.734)	(-4.497)
γ_{11}		0.437	2.651***	3.023**	1.855**	-0.848**	-3.933**
		(-0.844)	(-0.787)	(-1.282)	(-0.868)	(-0.424)	(-1.685)
Regime 2							
μ_2	-0.465*	-0.669**	-0.728**	-0.299	-0.363	-0.336	-0.373*
	(-0.278)	(-0.34)	(-0.322)	(-0.24)	(-0.248)	(-0.239)	(-0.222)
σ_2	1.998***	1.939***	1.935***	1.885***	1.91***	1.974***	1.859***
	(-0.3)	(-0.184)	(-0.334)	(-0.324)	(-0.165)	(-0.444)	(-0.255)
α_{22}	2.829***	3.662***	0.603	1.993***	3.017***	6.581***	5.484**
	(-0.672)	(-1.009)	(-1.018)	(-0.613)	(-0.77)	(-1.626)	(-2.223)
γ_{22}		-1.741*	-0.564	-0.286	-0.832	2.898***	2.217**
		(-0.913)	(-0.386)	(-0.625)	(-0.543)	(-0.953)	(-1.12)
Lag l		3	0	1	1	1	3
AIC		2.541	2.523	2.525	2.534	2.522	2.49
LL	-788.474	-782.903	-780.323	-780.936	-783.986	-780.28	-771.2
LR stat		11.143	16.303	15.077	8.977	16.389	34.549
p-value		[0.000]	[0.001]	[0.000]	[0.008]	[0.000]	[0.000]

Notes: *, ** and *** denote significance at 10, 5 and 1%, respectively. Standard errors of parameters are reported in parentheses (.), while p-values are displayed in brackets [.]. Regimes 1 and 2 correspond to the normal and turbulent regimes, respectively. The bootstrapped critical values at 10%, 5%, and 1% are 7.1663, 9.4967, and 13.1787, respectively.

As summarized in Table 2, results show that the variables affecting the dynamics of the RE stock prices strongly depend on the regime in which the latter is. Interestingly, SOVX and BANX are two exceptions for which both coefficients are significant in both regimes. These two variables seem to differ from the others by exerting a significant effect on RE stock prices in both regimes. Concerning the former, an increase in the sovereign CDS spread in calm periods raises the probability that the RE market falls in the crisis regime ($\gamma_{11} < 0$), while it maintains the RE sector in crisis in turmoil periods

($\gamma_{22} > 0$).

For BANX, the performance of the RE sector is particularly sensitive to bank financial distress during the crisis ($\gamma_{22} > 0$). More precisely, the probability of staying in the bear regime tends to unity if bank CDS increases (i.e. abrupt transition of p_{22} in Figure 9(b)). The underlying intuition is that a higher credit risk in the banking sector is generally associated with a higher liquidity risk, which leads banks to limit their credit supply (see, e.g., Annaert et al. 2013). However, the TVTP-MS model with BANX is not able to distinguish the conditional means between the two regimes because the coefficients μ_1 and μ_2 are not significant. Moreover, this is the only variable for which the coefficient is significant but the realizations enabling transition are never reached (see Appendix, Figures 5 to 9) - meaning that the level of bank distress that would be necessary for the RE sector to switch from the calm to the turbulent regime is never reached over the period under analysis. Therefore, we do not consider the effect of bank credit risk in the calm regime to be economically significant.

The other macrofinancial variables we consider also significantly affect RE stock prices but in only one of the two regimes. Oil prices, the performances of high-technology companies, as well as those of the overall market play a significant role on RE stock prices, but only when the latter is in a calm period (γ_{11} is significant while γ_{22} is not), whereas the emissions permit prices in Europe only matter in a turbulent period (γ_{22} is significant while γ_{11} is not).

Regarding oil prices, we find that a rise in Brent oil prices increases the probability that the clean energy sector stays in this bull regime ($\gamma_{11} > 0$). Therefore, higher oil prices have a significant positive impact on the stocks of RE companies during stable periods. This result can be explained by the fact that higher oil prices make RE more competitive relative to conventional energy, and hence encourage capital flows to move to the alternative energy sector.[19] Our results contribute to a literature that finds either no effect or a positive effect of oil prices on the RE market (see, e.g., Henriques and

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[19] Similar results are obtained when WTI oil prices are used. Nonetheless, the Brent oil prices are more relevant as we focus on the European stock market.

Sadorsky 2008 or Kumar et al. 2012). In line with Managi and Okimoto (2013) and Reboredo et al. (2017), we conclude in favor of a time-varying dependence between oil and RE stock prices.

In the same way, the stock market performance of high-technology companies (ETX) positively affects the RE sector in Europe only in calm periods. More precisely, ERIX is more likely to stay in the bull regime ($\gamma_{11} > 0$) when ETX increases. This result underlines a complementarity between the two sectors, which is in line with the findings of Henriques and Sadorsky (2008), Sadorsky (2012), Managi and Okimoto (2013), Reboredo (2015), and the references therein. In normal periods, the technology sector appears to be a way for investors to evaluate the future performance of the clean energy sector. This may be due to the key role that technological advances play in RE efficiency.

Regarding the Euro Stoxx 50 index (ESX), used here as a proxy for the general state of the financial market, its variations positively influence the RE market in calm periods. More specifically, when the ESX index increases, the ERIX index is more likely to stay in the calm regime ($\gamma_{11} > 0$). In a turbulent period, investors appear not to use the ESX index anymore to evaluate the RE future returns.

Finally, an increase in the European carbon prices, captured by CARBIX, leads to a higher probability of leaving the crisis regime. The intuition behind this result is that a higher carbon price implies a larger cost of using carbon-intensive energy, improving RE investments' attractiveness. Nevertheless, the European cap and trade system did not significantly affect the behavior of investors as regards RE in the bull regime between 2008 and 2019. This could be due to the lack of scarcity of allowances in the first phases of the EU emission trading scheme. The price of allowances being already very low, a large enough decrease to hamper the attractiveness of RE is unlikely.

4.2. The particular role of sovereign risk

4.2.1. z-tests and regime-dependent indicators

To compare the effect between the information variables, we rely on the regime-dependent indicators and the relative magnitude of coefficients using z-tests. As explained in Section 3.3, the regime-dependent indicators are based on γ and α coefficients and allow us to interpret the non-linear relationship between the transition probabilities and the information variables (see Eq. 4). Figure 4 shows this relationship for each value of SOVX and the time-varying transition probabilities.[20] Finally, z-tests provide a statistical test to check if there is a significant difference in the effect of each information variable.

We find that MMP is equal to -0.983 for SOVX in regime 1. This implies that the decrease in SOVX of one standard deviation from ZM ($SOVX = 2.934$) increases the probability of staying in the calm regime by 0.983. In the same way, when SOVX increases, the probability of falling in the crisis regime increases by 0.983. Consequently, in this specific case, ERIX is very likely to fall into a turbulent regime following a rise in sovereign default risk. Compared with all other variables, SOVX is found to be the most impactful information variable.

The results are quite similar in regime 2. For instance, when SOVX increases by one standard deviation from ZM (SOVX = 2.474), the probability of staying in the crisis regime increases by 0.554. Since this marginal probability is higher than 0.5, it is most likely to observe ERIX in the turbulent regime following a rise in SOVX.

As depicted in Table 4, using z-tests enables us to conclude that the coefficient of SOVX is significantly higher than all the other significant coefficients, in both regimes 1 and 2 (corresponding, respectively, to calm and crisis periods). We note an exception during crisis periods, in which bank risk has an effect of similar magnitude.

Figure 4 clearly illustrates the evidence mentioned above and the regime-switching behavior of ERIX according to SOVX. What is particularly obvious in Figure (4c) is that transition probabilities to stay in regime 1 fall on several occasions from 2008 and 2012 which corresponds to periods where positive variations in SOVX were the most important. We observe the inverse pattern when SOVX decreased after 2012.

Figure 3 displays the computed difference between the ERIX regime probabilities as

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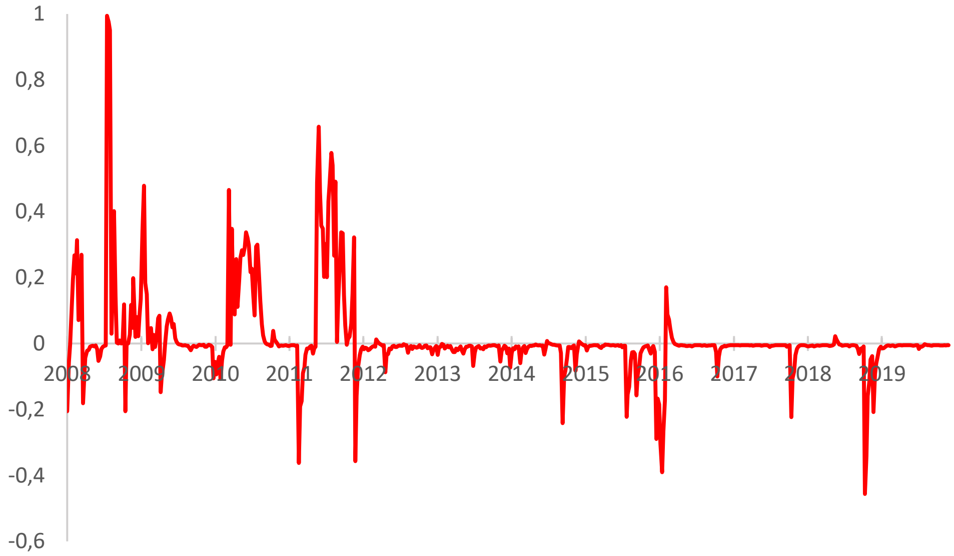
[20] The time-varying transition probabilities estimated with other information variables are available in the appendix (Figures 5-9).

Figure 3: Contribution of SOVX in the estimation of probabilities in turbulent regime



Notes: A positive difference indicates that the estimated probabilities of regime 2 are higher when SOVX acts as an information variable and then, contributes to detecting turbulent regime of ERIX.

estimated by the SOVX and the FTP-MS models. The advantage here is that it illustrates the contribution of SOVX in the detection of turbulent regimes for each period. We observe that the most important contribution of SOVX corresponds to the years 2008, 2010, and 2011 which support the significant information brought by sovereign risk in the detection of turbulent episodes of ERIX, especially during the subprime and European debt crises. However, we see that the difference for other periods is close to zero which can be explained by the fact that SOVX started to decrease in 2012 and remained low through the rest of the sample.

Putting all the results together, sovereign risk is the only variable that has a significant effect on RE returns in both calm and turmoil periods. SOVX turns out to be the main determinant of RE returns in both regimes and appears as the most important determinant for RE stock prices in Europe.

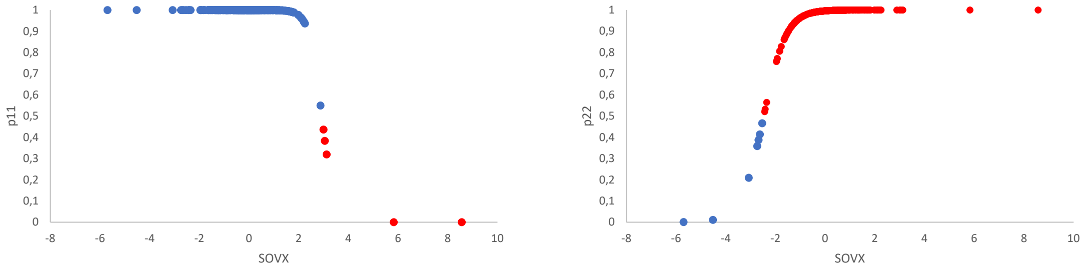
Table 3: Regime-dependent indicators

	CARBIX	BRENT	ETX	ESX	BANX	SOVX
ZM_{11}	-11.364	-1.713	-2.073	-2.839	6.344	2.934
MMP_{11}	0.109	0.663	0.756	0.464	-0.212	-0.983
ZM_{21}	-11.364	-1.713	-2.073	-2.839	6.344	2.934
MMP_{21}	-0.109	-0.663	-0.756	-0.464	0.212	0.983
ZM_{22}	2.103	1.069	6.969	3.626	-2.271	-2.474
MMP_{22}	-0.435	-0.141	-0.072	-0.208	0.725	0.554
ZM_{12}	2.103	1.069	6.969	3.626	-2.271	-2.474
MMP_{12}	0.435	0.141	0.072	0.208	-0.725	-0.554

Table 4: Comparing the variables with help of z-tests

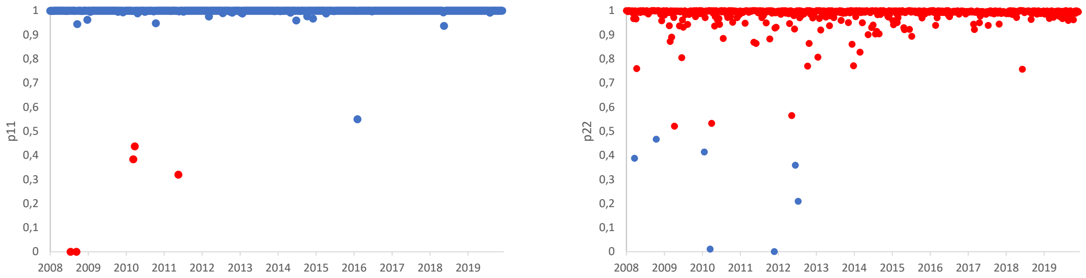
	z-statistics	Interpretation
Comparing γ_{11}		
BRENT/SOVX	3.54	$BRENT < SOVX$ $(2.651 < \|-3.933\|)$
ETX/SOVX	-3.29	$ETX < SOVX$ $(3.023 < \|-3.933\|)$
ESX/SOVX	3.05	$ESX < SOVX$ $(1.855 < \|-3.933\|)$
Comparing γ_{22}		
CARBIX/SOVX	-2.74	$CARBIX < SOVX$ $(\|-1.741\| < 2.217)$
BANX/SOVX	0.46	$BANX = SOVX$ $(2.898 \approx 2.217)$

Figure 4: The non-linear relationship between ERIX and SOVX



(a) Variations in SOVX and the probability of staying in the first regime

(b) Variations in SOVX and the probability of staying in the second regime



(c) The time-varying probability p_{11} led by SOVX

(d) The time-varying probability p_{22} led by SOVX

Notes: The red part of the plot lines corresponds to situations where the probability of staying or falling in regime 2 is higher than the probability of falling or staying in regime 1. The blue part represents the opposite case.

4.2.2. *Forecasting analysis*

In this part of the paper, we compare the in-sample forecasting performance of all information variables with the aim to determine the best predictors of ERIX regime probabilities, as a complement to the analysis done previously. First, we compute for each information variable the one-step-ahead in-sample forecasts of ERIX. Then, we compute the Root Mean Square Error (RMSE) to compare the forecast error measurement of each TVTP-MS model, including the FTP-MS. The results are displayed in column 1 of Table 5 and show that the highest RMSE corresponds to the FTP-MS model. As we are unable to affirm that all these forecasting performances are statistically different, we apply the Model Confidence Set (MCS) of Hansen et al. (2011). This approach determines a subset that contains the unknown best predictor with some confidence level (we retain 95% in the following), meaning that all predictors in the subset are not significantly different from the true best predictor. The results displayed in column 2 of Table 5 show that the subset includes the BRENT, CARBIX, ETX, and SOVX models. On the opposite, the FTP-MS and the two other TVTP models (ESX and OIL) are excluded from the subset containing the best predictor. Consequently, we can claim that the former four variables provide the most meaningful information when it comes to predicting the non-linear dynamics of ERIX returns.

We then use the four best models identified by the MCS to build a four information variables TVTP-MS model and we investigate the in-sample performance of this new model. After applying the MCS (see Table 6), we find that the confidence set remains unchanged except that the augmented model now enters the set, while ETX is excluded. This means that the four variables model does not outperform the best univariate models identified in Table 5. We observe, however, that SOVX is the univariate model with the highest p-value, at least 6-fold higher than the others. It suggests that with a more restrictive confidence level, SOVX is the only variable included in the confidence set.

We also analyze the goodness-of-fit of this new model but here we use the SOVX model to define the null hypothesis of the LR test. The bootstrapped critical values at 10%, 5%, and 1% are, 28.667, 33.314, and 43.004 respectively, while the LR statistic is 18.706, revealing that the four variables model fits worse than the SOVX model.[21]

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[21] As our objective is rather to evaluate the non-linear impact of each information variable on the dynamics of the ERIX index, and given that this augmented model does not outperform the univariate ones, we do not report the results in the paper. They remain available upon request.

Table 5: Forecasting analysis and Model Confidence Set

Models	RMSE	MCS p-values
FTP-MS	0.977	0.0319
BANX	0.972	0.0319
ESX	0.972	0.0319
BRENT	0.953	0.8048
CARBIX	0.960	0.9475
ETX	0.971	0.9475
SOVX	0.962	1
Excluded	FTP-MS, BANX, ESX	
Included	FTP, BRENT, CARBIX, ETX, SOVX	

Notes: RMSE are reported in column 1. Model Confidence Set p-values are reported in column 2 and a 90% confidence level is retained to determine which variables are included in the confidence set.

Table 6: Model Confidence Set including the 4 variables model

Models	MCS p-values
FTP-MS	0.0354
BANX	0.0354
ETX	0.0354
ESX	0.0354
BRENT	0.0739
CARBIX	0.0739
SOVX	0.5078
4 variables	1
Excluded	FTP-MS, BANX, ETX, ESX
Included	BRENT, CARBIX, ETX, SOVX, 4var.

Notes: A 90% confidence level is retained to determine which variables are included in the confidence set.

4.3. Further analysis of the role of sovereign risk

The results detailed above prove that SOVX has been a key determinant of the performance of the renewable energy sector. SOVX is the only variable that affects ERIX in both regimes, while the shape and magnitude of the effect are significantly greater than those of the other information variables. The forecasting analysis and all the tests, including the LR test, MCS, and z-tests, prove that SOVX is the most relevant information variable to describe ERIX's time-varying transition probabilities from 2008 to 2019.

The intuition behind this striking result is that investors expect that pressure on public debt will affect public support for RE. While changes in energy policies may arise for different reasons, a large pressure on public finances is likely to entail a brake on the public support for RE. Such a decrease was effectively observed during the two crises (FS-UNEP 2012; 2014). In addition, Azqueta-Gavaldón et al. (2023) show that the sovereign debt crisis in Europe went hand in hand with an increase in uncertainty, about economic policies and, more particularly, about energy policies.

Sovereign risk may therefore have had an impact on the renewable energy sector by creating uncertainty about energy policies. Anticipated changes in these policies can shift the perceived balance between risk and return for investments in RE. It may increase the perceived risk and/or decrease the perceived profitability of the RE sector, as suggested by existing studies highlighting how investors react to changes in energy policies (see, e.g., Hofman and Huisman 2012, Wüstenhagen and Menichetti 2012, Ritzenhofen and Spinler 2016, Ang et al. 2017). For example, Ritzenhofen and Spinler (2016) show that the switch from a feed-in tariff policy to a free market regime leads investors to reduce or even withdraw their investments. In addition to uncertainty regarding the future kind of regulation, uncertainty as regards the extent and the continuity of public policy may also play a key role. Such a result is found by the literature (see, e.g., Lüthi and Wüstenhagen 2012, Wüstenhagen and Menichetti 2012). The policies that are associated with a low perceived risk for investors, through policy stability and/or the duration of support, imply lower financing costs for RE projects and are thus more likely to foster RE investments.

Based on these arguments, we investigate if the uncertainty linked to the energy policy of European governments and to the EU regulation can affect the RE markets. We use two indexes computed by Azqueta-Gavaldón et al. (2023) capturing uncertainty levels in the euro area: The uncertainty regarding European regulation (ERPU) and that concerning energy policies in the EU (ENPU).[22] The dataset stopped in the last week of May 2019 and is available at a monthly frequency.[23]

First, we perform a principal component analysis (PCA) on SOVX, ENPU, and ERPU to capture the shared information and then, use it as an information variable. The results are presented in Table 7. We observe that the first principal component $PC1$ (i.e. the derived variable formed as a linear combination of the three variables) captures 37% of the total variance of ENPU, ERPU, and SOVX. $PC1$ is thus an important indicator of the information included in the three variables, which is confirmed by their positive correlation. While the uncertainty about policies is explained by many factors, this analysis reveals that the sovereign risk is closely related to European regulation and energy policy uncertainty between 2008 and 2019. This is consistent with the idea that investors rely on stable and consistent policy frameworks to make long-term investment decisions in particular in renewable energy projects. Second, using $PC1$ as an information variable of our TVTP estimation, we find that the combination of SOVX, ENPU, and ERPU increases the probability of staying in a crisis regime ($\gamma_{22} > 0$). Policy uncertainty may thus be a relevant channel explaining why sovereign risk slowed the recovery of the renewables sector during the crisis.

As a conclusion, a high level of sovereign risk makes it more likely budget cuts for RE, while the behaviors of investors in the European RE sector appear to be highly in-

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[22] The authors rely on the popular method designed by Baker et al. (2016) to compute uncertainty concerning European regulation and energy policies (e.g. carbon taxes, feed-in-tariffs, and tax incentives for energy-related R&D). As detailed in their paper, they collect the most relevant European regulation-related keywords and energy-related keywords from the main EU country newspapers to compute uncertainty. These keywords include, among others, Brexit, Brussels, or parliament for the former, and climate protection, pollution, gas, or petrol for the latter. On the one hand, the ENPU variable directly represents the uncertainty about the energy market discussed above. On the other hand, considering the ERPU variable enables us to capture the strain on European institutions that may be linked to the sovereign crisis, and that may lead to a decrease in the Union's capacity to support common projects - particularly in energy-related matters.

[23] We compute the log-standardized weekly returns of ENPU and ERPU. To combine these data with the weekly data used in previous sections, we transform these monthly data into weekly frequency according to the Denton method. We choose the Europe Vstoxx as a driving higher frequency indicator (weekly) to guide the extrapolation of monthly data. This indicator is well suited here as it reflects investor sentiment and overall economic uncertainty at the European level. The data are collected from Thomson Reuters Eikon.

fluenced by public policies (see the aforementioned references). The spread of sovereign risk, and the associated pressure on public finances it represents, hence fosters RE policy uncertainty, which makes investors reluctant to invest in RE. We suggest that such a mechanism may explain the difficulty for this market to rebound after the subprime crises.

Table 7: Principal component of European sovereign risk and energy policy uncertainty and its effect on ERIX

Part a- Principal component analysis:

Eigenvalues:

Number	Value	Proportion	Cumulative
PC1	1.095	0.365	0.365
PC2	0.905	0.336	0.701
PC3	0.905	0.299	1

Eigenvectors (PC1):

SOVX	0.470
ENPU	0.513
ERPU	0.718

Part b- TVTP-estimates:

Regime 1		Regime 2	
μ_1	0.064*	μ_1	-0.523**
	(0.034)		(0.264)
σ_1	-0.279***	σ_1	0.694***
	(0.036)		(0.694)
α_{11}	5.201***	α_{22}	9.217**
	(1.048)		(2.216)
γ_{11}	0.923	γ_{22}	0.126**
	(0.736)		(2.478)
Lag l	1		
AIC	2.56		
LL	-751.65		

Notes: *, ** and *** denote significance at 10, 5 and 1%, respectively. Standard errors of parameters are reported in parentheses (.). Regime 1 and Regime 2 correspond to the normal and turbulent regime, respectively.

5. Conclusion

While existing research usually focuses on oil and technology as potential determinants of RE stock price variations, the present paper aims to examine the role of the broad macrofinancial environment. We focus on the 2008 to 2019 period which includes a significant historical period regarding the sovereign debt crisis and the financial challenges that many European countries faced. In this context, we pay particular attention to the role of sovereign debt, and we investigate whether the potential determinants of the RE market are the same during the calm and turmoil periods through which the RE sector evolves. For that, we use a time-varying transition probability Markov-switching model, which enables us to examine how each macrofinancial variable can affect the probabilities of switching from one regime to another.

Our main findings are threefold. First, most of the macrofinancial information variables we consider affect the renewables only in one of the two regimes (calm or turbulent). In line with previous studies, we find that the markets identified as competing and complementary to RE firms, i.e. oil and technology, respectively, are key determinants of RE in Europe in the calm regime. However, they no longer impact the RE firms' performance when the latter is in a turmoil period. In the same way, the performance of leading European companies has a significant and positive effect on renewables but only when bull market conditions are observed on the RE market. On the opposite, we find that an increase in carbon permit prices and a fall in bank credit risk have a significant effect on the RE sector only in crisis, by fostering the probability of leaving this regime.

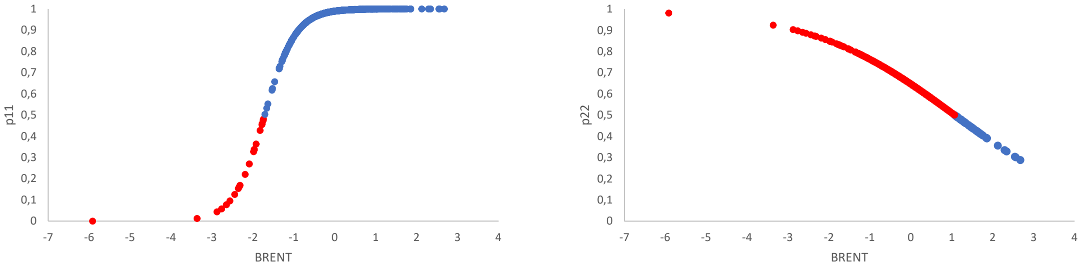
Second, we reveal that public financing conditions, captured by sovereign risk, are the only factors affecting the RE sector in both calm and turbulent periods. Pressure on sovereign debt adversely affects the RE sector. More precisely, an increase in such a pressure leads to a higher probability of switching to a turbulent regime and of staying in such turmoil. This could be explained by restrictive RE policies due to financial constraints, as well as the energy policy uncertainty entailed on the RE market, which is found to be detrimental to the development of low-carbon energy.

Finally, through a forecasting and comparative analysis with several macrofinancial factors, we emphasize that the stress on public debt is the main driver of the RE market in Europe during the period under analysis (2008-2019). Despite that most of RE investments are from private sources, our paper show the key role of public finance on the performance of the RE sector in both calm and crisis periods.

With help of the literature and of a complementary analysis, we support the idea that investors in the European RE market pay close attention to the support provided by public policies to this sector. An increase in sovereign risk puts a strain on public finances that may generate uncertainty about RE policies, which alters the perception of the risk-return ratio of RE investments. A long-term public engagement to the RE sector is hence essential to sustain the upward trend in the renewable energy sector needed to satisfy the EU objectives. An avenue for future research would be to explore if and how public authorities could define energy transition policies solid enough to anchor investor confidence in the renewable energy sector, even in periods of turmoil, in order to achieve the challenging energy transition pathway.

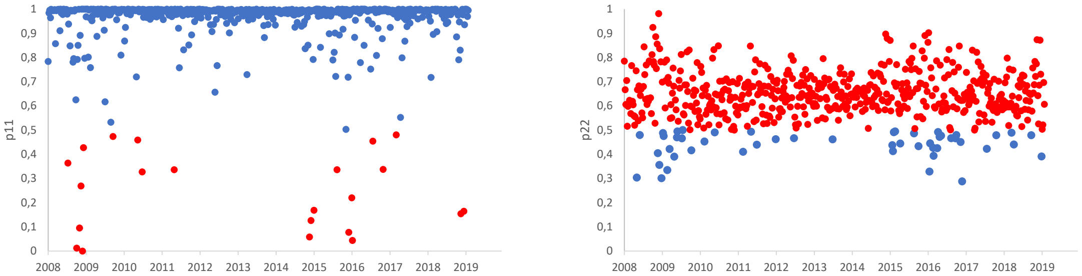
6. Appendix

Figure 5: The non-linear relationship between ERIX and BRENT



(a) Variations in BRENT and the probability of staying in the first regime

(b) Variations in BRENT and the probability of staying in the second regime

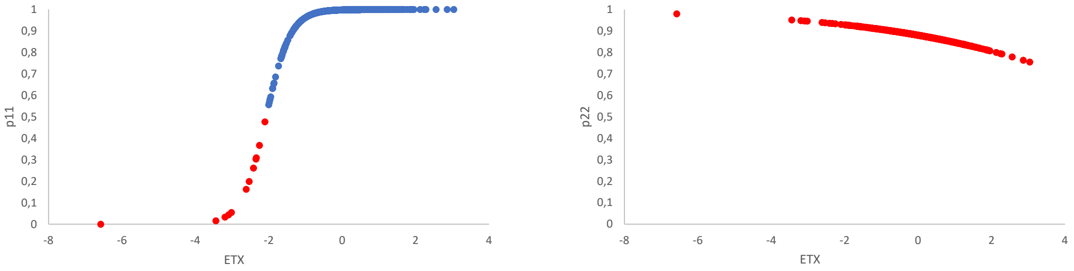


(c) The time-varying probability p_{11} led by BRENT

(d) The time-varying probability p_{22} led by BRENT

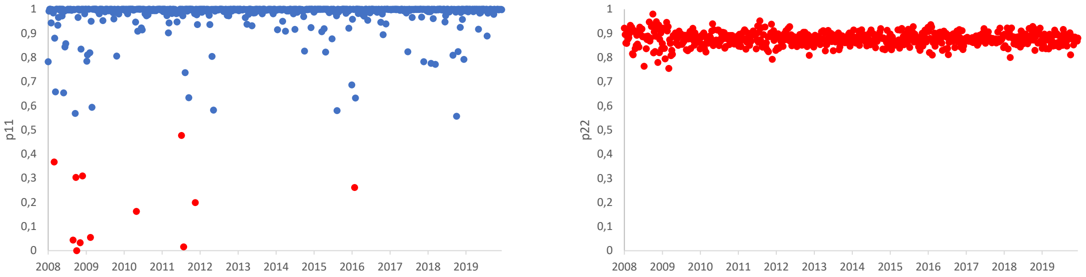
Notes: The red part of the plot lines corresponds to situations where the probability of staying or falling in regime 2 is higher than the probability of falling or staying in regime 1. The blue part represents the opposite case.

Figure 6: The non-linear relationship between ERIX and ETX



(a) Variations in ETX and the probability of staying in the first regime

(b) Variations in ETX and the probability of staying in the second regime

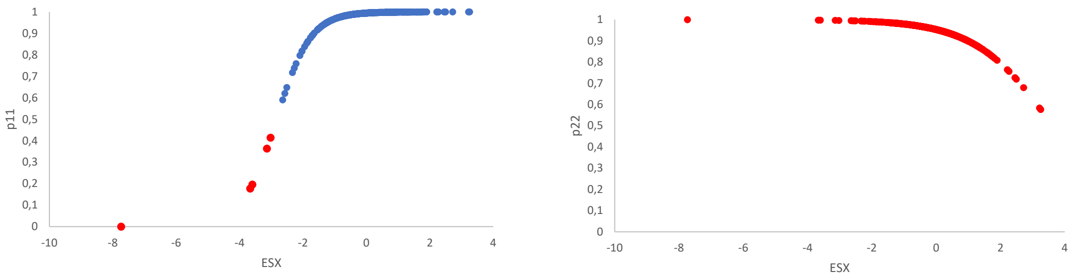


(c) The time-varying probability p_{11} led by ETX

(d) The time-varying probability p_{22} led by ETX

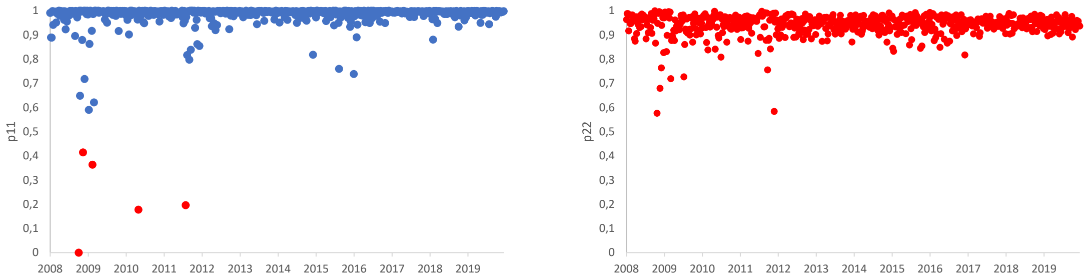
Notes: The red part of the plot lines corresponds to situations where the probability of staying or falling in regime 2 is higher than the probability of falling or staying in regime 1. The blue part represents the opposite case.

Figure 7: The non-linear relationship between ERIX and ESX



(a) Variations in ESX and the probability of staying in the first regime

(b) Variations in ESX and the probability of staying in the second regime

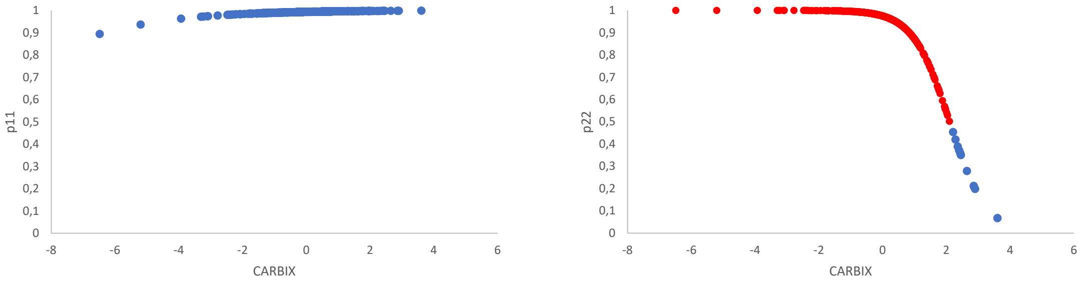


(c) The time-varying probability p_{11} led by ESX

(d) The time-varying probability p_{22} led by ESX

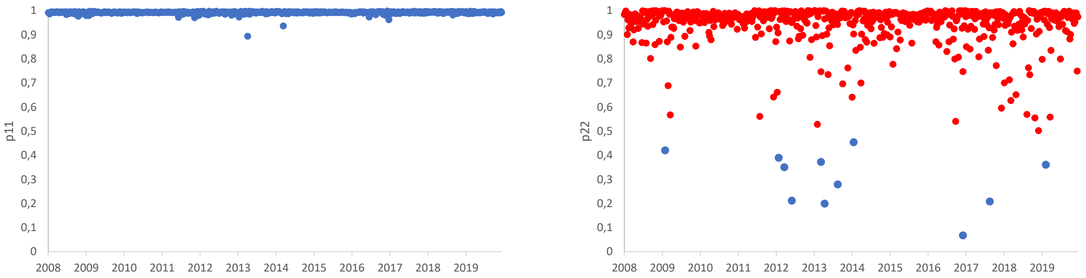
Notes: The red part of the plot lines corresponds to situations where the probability of staying or falling in regime 2 is higher than the probability of falling or staying in regime 1. The blue part represents the opposite case.

Figure 8: The non-linear relationship between ERIX and CARBIX



(a) Variations in CARBIX and the probability of staying in the first regime

(b) Variations in CARBIX and the probability of staying in the second regime

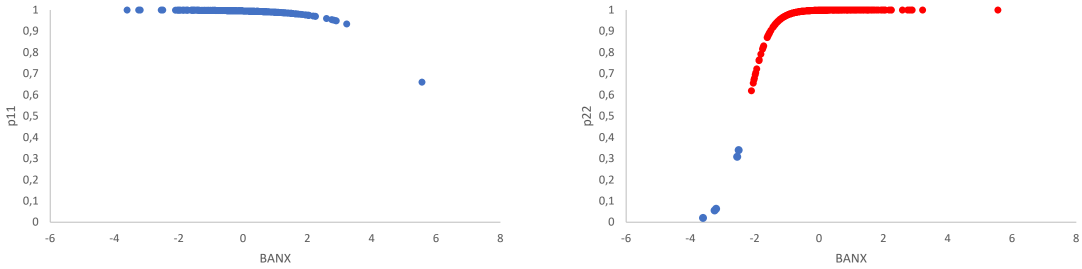


(c) The time-varying probability p_{11} led by CARBIX

(d) The time-varying probability p_{22} led by CARBIX

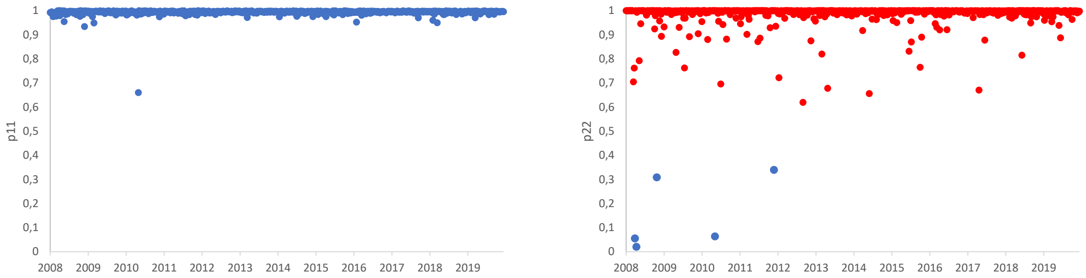
Notes: The red part of the plot lines corresponds to situations where the probability of staying or falling in regime 2 is higher than the probability of falling or staying in regime 1. The blue part represents the opposite case.

Figure 9: The non-linear relationship between ERIX and BANX



(a) Variations in BANX and the probability of staying in the first regime

(b) Variations in BANX and the probability of staying in the second regime



(c) The time-varying probability p_{11} led by BANX

(d) The time-varying probability p_{22} led by BANX

Notes: The red part of the plot lines corresponds to situations where the probability of staying or falling in regime 2 is higher than the probability of falling or staying in regime 1. The blue part represents the opposite case.

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