

Revising the Connectedness between Oil, Natural Gas and Energy Firms: A Quantile-decomposition Approach

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Abstract

We investigate the returns connectedness between 118 energy firms of 10 of the most relevant countries on energy consumption, and the natural gas and oil prices for the period between January 3, 2006 and December 15, 2023. Based on a novel combination of the quantile connectedness and spillover decomposition approaches, our results demonstrate that the natural gas, oil and energy stock markets are closely interconnected, mainly in bearish and bullish scenarios. Almost a quarter of the total spillover at the country-level comes from the interaction between stock and fuel markets, but such contribution is reduced to less than 4% when the network is configured at firm-level. Energy stock markets of the United States, Canada, Italy, Spain and the United Kingdom are the main shocks transmitters, while Japan and China are net receivers within the global energy network. Oil and natural gas can be important alternatives for risk diversification, mainly in medium and low return scenarios. We also identify the most and least vulnerable energy sectors and firms in the entire network in each scenario, establishing precise recommendations for the design of energy policies and investment decision-making.

Keywords: returns, spillovers, energy, network.

JEL codes: G11, G15, G18.

Declarations of interest: none.

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1. Introduction

Fossil fuels such as oil and natural gas have played a key role in industrial and worldwide economic development. According to Global Energy Trends (2024), crude oil and natural gas, two of the main energy sources globally, accounted for 30% and 23% of global energy consumption in 2022, respectively⁵. Given this scenario, it is evident that the dominant role of these fuels in the countries industrialization, added to the financialization phenomenon that affects them, has strengthened their links with other financial markets and facilitated the risks transmission, especially in periods of high financial turbulences (Zhang, 2017; Fernández et al., 2018). Beyond its influence on investment decisions, this strong link has also been crucial in the debate and development of the energy transition process in the world. The environmental and economic damage linked to climate change has led various countries to establish regulations to accelerate the energy transition towards renewable sources, and naturally, reduce their exposure and dependence on fossil energies such as oil and natural gas. This is why monitoring the links between fuels and other financial markets, such as stock markets, becomes vitally important for the design of investment strategies as well as for the energy policies design.

The literature that has studied the link between stock markets and fuels such as oil and natural gas has experienced significant development in the last decade. Much of it attributes the high dependence between these markets to: *i*) an input-output channel through which increases in fuel prices reduce the cash flows and stock prices of firms, especially those linked to the energy sector (Naeem et al., 2020; Geng et al., 2020); *ii*) a financial channel that propagates shocks between the stock and fuel markets, forcing investors to modify their profit expectations and rebalance their portfolios (Acaravci et al., 2012; Geng et al., 2021; Dai and Zhu, 2022); and *iii*) a long-term channel that cyclically links the path of stock and fuel prices to macro-variables such as growth, private consumption and inflation (Ramberg and Parsons, 2012; Fernández et al., 2018). Despite important advances, international evidence is not exempt from limitations, and particularly, our research addresses two important knowledge gaps that differentiate it from existing studies. First, much of the researches that have studied this relationship has used aggregate indices or very small samples of energy companies under a mean-conditional connectedness approach (Khalifaoui et al., 2015; Wang and Wu, 2018; Maitra et al., 2021; Mensi et al., 2021b). Naturally, all these studies have not only overlooked the interconnections structure between these actors in extreme scenarios or different from those considered normal, but have also failed to establish the systemic relevance of certain companies or markets within the energy network since a global perspective. Thus, to provide a more complete description of the network in different scenarios, we leverage the advantages of the Quantile Autoregression Vector (QVAR) approach introduced by Ando et al. (2022) for a system composed by oil and natural gas prices as well as by stock prices of a large set of energy companies. Second, all previous studies have ignored the interdependence origin between these markets, overlooking the contribution to the total connectedness of both the internal interconnections of each specific-market and the interactions between them. That is why, after estimating the spillover in each quantile of interest, we decompose the total connectedness using the

⁵ See website <https://datos.enerdata.net/gas-natural>

Gabauer and Gupta (2018)'s method, establishing the internal or external nature of the links. This distinction, as well as the evaluation of the global energy network in different risk scenarios, is of special interest to investors and regulators due to its impact on investment strategies and the design of energy policies.

In light of these motivations, we study a system comprised of oil, natural gas and 118 energy companies from 10 of the countries with the largest participation in global energy consumption (Canada, United States, China, Japan, France, Germany, Italy, Norway, Spain and the United Kingdom). Our daily data set spans between January 3, 2006 and December 15, 2023, a period that covers important events of systemic relevance such as the Global Financial Crisis and the recent Covid-19 Pandemic. In methodological terms, we novelly combined the quantile connectedness approach introduced by Ando et al. (2022) and the spillover decomposition method proposed by Gabauer and Gupta (2018) to explore the links between energy stock markets and fuel prices. From this novel combination, we can obtain the popular spillover statistics formulated by Diebold and Yilmaz (2012, 2014) for the different quantiles of the returns distribution, and distinguish the contribution to the total system connectedness on a global scale, both from the spillovers internal of each market as well as external ones. In order to achieve a more detailed description, our analyzes are replicated at the level of firms, sectors and countries, using for the latter two cases the returns of an equally-weighted portfolio comprised of the firms that belong to a specific sector or market. Naturally, this type of contrast allows us to capture the heterogeneity of interconnections under different structures and provide a more robust analysis of the global energy network.

Our research provides four original contributions to the existing literature. First, the connectedness between the oil, natural gas and stock markets is intense, and varies both over time and across different quantiles of the return distribution. For the 95%, 50% and 5% quantiles, the total connectedness measures were 86.9%, 50.8% and 87.4% in the country-level system; 75.4%, 37.2% and 75.5% in the sector-level system; and 99.1%, 98.9% and 99.1% at the firms-level, respectively. These spillovers intensified during periods of financial stress such as the Global Financial Crisis, European Sovereign Debt Crisis and the recent Covid-19 Pandemic. These findings also encompass other important contributions to investment decisions and the design of energy policies: *i*) both at the level of countries and sectors, the connectedness between fuel and energy stock markets is more intense and symmetrical in extreme quantiles and lower in intermediate ones; *ii*) at the firms-level, spillovers are much more intense and symmetrical across the different quantiles of the return distribution than what is observed at the level of countries or sectors; *iii*) after decomposing the connectedness measures, we observe that the incidence of specific-market spillover (internal) on the total interdependence of the energy system is more relevant than cross-market spillover (external). This suggests that most of the system's connectedness comes from the links developed within each market, mainly within the energy stock markets; *iv*) despite the lesser role of cross-market spillover, its incidence is more evident at the country or sector level, and it fades drastically at the firms-level, which evidently provides a better evaluation of the diversification possibilities of energy portfolios.

Second, the actors most connected and vulnerable to the shocks transmission are precisely identified within the global energy network. These actors are located in the central areas of the network and transmit the most intense shocks of the system. The energy stock

markets of North America (United States, Canada) and Europe (United Kingdom, Italy, Spain, France, Germany, Norway) are the main shocks transmitters in both bullish and bearish scenarios. In quantiles close to the average, these markets continue to be the main protagonists for the risks spread, although with less intense spillovers. The Oil and Gas Producers (OP) and Oil and Gas Services (OS) sectors, mainly from the United States, Canada, Spain and the United Kingdom, are the most important in the transmission of spillovers in both bullish and bearish scenarios. The findings at the firm-level showed an active participation of US energy firms in the shocks transmission across the different quantiles. The relevance of these markets, sectors and firms naturally limits not only diversification opportunities but also restricts the effectiveness of energy transition policies.

Third, the least connected markets, sectors and firms in the energy system are also identified. These actors are located in the peripheral areas of the global network, a position from which they are less vulnerable to the shocks transmission from the rest of the system. China and Japan stand out as the energy stock markets least connected to the global network through the different quantiles of the returns distribution. The renewable energy (RE) and utilities (UT) sectors are the least vulnerable energy sectors in the system, mainly in the extreme quantiles. At firm-level, the description of diversification opportunities was more heterogeneous between quantiles and countries. In bullish scenarios, various Canadian, Spanish, Italian and British companies constitute an important set of opportunities to diversify risk in energy portfolios; while in the mean and low return quantiles, Chinese firms are the less vulnerable actors.

Fourth, the roles of natural gas and oil within the global energy network are also established. It is important to mention that the external spillover of fuel on the energy stock markets is more relevant at the level of countries and sectors, since at the firms-level its incidence generated a cross-market spillover of less than 4% in the different quantiles. Despite this, the oil and natural gas markets stood out for being among the least interconnected actors in the networks at the level of countries and sectors throughout the different quantiles of the returns distribution, a fact that makes them important diversification alternatives. Crude oil transmits more relevant shocks than natural gas, and its impact on the global network is particularly greater in extreme scenarios (bullish and bearish). Naturally, this type of incidence reveals the importance of developing flexible energy policies tailored to market conditions.

The rest of the paper is structured as follows. Section 2 presents the literature review in the field. Section 3 presents our data, while Section 4 details our methodological approach. Section 5 shows our main results, and finally, Section 6 contains the conclusions and implications of this research.

2. Literature review

The literature that has addressed the connectedness analysis between stock markets and fuels such as oil and natural gas is very extensive, and its scope has left important lessons for investment decisions and the design of energy policies. Here, we present the literature that has addressed the link between stock markets and oil and natural gas prices. The first two sections address the abundant studies focus in mean-conditional

connectedness approaches, in which methods such as copulas analysis (Wen et al., 2012; Ji et al. 2018a), multivariate GARCH (Khalfaoui et al., 2015; Boldanov et al., 2016), time-frequency analysis (Geng et al., 2020; Asadi et al., 2022), and the traditional method of Diebold and Yilmaz (2012, 2014) and its adaptations (Maghyereh et al., 2016; Wang and Wu, 2018; Chuliá et al., 2023) have been very popular. The final section presents the most recent studies on the interdependence between these markets based on modern quantile connectedness approaches.

2.1. Background on the link between oil and stock markets

The link between oil and stock markets has been of great interest to the international academic community due to its impact on climate change. Naturally, oil is the most in-demand fossil fuel, and according to data obtained from the U.S. Energy Information Administration, in 2022 alone it represented more than 30% of global energy consumption, a figure equivalent to almost 100,000 million barrels per day⁶. This systemic relevance, together with its high financialization, establishes a clear link with the stock markets dynamics, mainly with energy firms.

A vast empirical literature has investigated spillovers between crude oil prices and stock markets using aggregate stock indices. Based on the copula method, Wen et al. (2012) showed that oil prices are closely interconnected with the US stock market, while their link with the Chinese market is lower. Subsequently, Khalfaoui et al. (2015) also found large spillovers between oil and stock markets of the G7 countries, a system within which the United States plays a crucial role in the shocks transmission. Boldanov et al. (2016) studied this link on the stock markets of the main oil exporting-importing countries (Canada, Russia, Norway, the United States, China and Japan). Their work corroborated not only the strong link between stock markets and oil, but also found that spillovers had an asymmetric impact between importing and exporting countries of this fuel. Awartani et al. (2016), who used the Diebold and Yilmaz (2012)'s method, demonstrated that oil transmits a spillover of 20.4% to stock markets, although its impact on currency and commodity markets is much more limited. Other studies based on aggregate stock indices also confirm these findings as well as the greater intensity of spillovers in times of crisis (Zhang and Wang, 2014; Maghyereh et al., 2016; Zhang, 2017; Ji et al., 2018a; Wang and Wu, 2018; Xu et al., 2019; Xie et al., 2021; Mensi et al., 2021b; Alkathery and Chaudhuri, 2021)

Other research has proposed the use of sectoral stock indices or stock prices of individual firms to analyze the connectedness between oil and stock markets. These types of analyses, unlike studies based on aggregate stock market indices, have provided notable advances by demonstrating the existence of a more heterogeneous response of various sectors or companies to oil shocks. Regarding studies based on sectoral indices, Arouri et al. (2011) analyzed the risks transmission between oil prices and various sectors of the US and European stock markets. Their findings revealed that oil shocks significantly impacted all sectors, except Automobile & Parts (Europe) and Industrials and Utilities (United States). Sadorsky (2012) demonstrated that the technology and clean energy sectors of the

⁶ For more details, visit the website of U.S. Energy Information Administration at <https://www.eia.gov/international/data/world/petroleum-and-other-liquids>

US stock market experience low spillovers with oil prices, a fact that facilitates risk diversification and the implementation of energy policies focused on the development of renewable energies. In emerging markets there are studies that have also provided similar results. Tiwari et al. (2018) developed a study for 13 sectors of the Indian stock market and concluded that the energy, materials and information technology sectors are less exposed to oil shocks. On the other hand, Mensi et al. (2021a) analyzed the dynamics between oil prices and 10 sectors of the Chinese stock market, and demonstrated that spillovers vary both across time and different sectors.

Studies based on a firm-level approach are more recent. Naturally, a perspective of this nature provides a more complete and detailed description of both shock transmission routes and diversification opportunities (Restrepo et al., 2018; Foglia and Angelini, 2020). So, Antonakakis et al. (2018) studied spillovers between oil prices and 12 of the largest energy firms in the world using the Diebold and Yilmaz (2012)'s method. Their findings revealed that spillovers are dynamic and unidirectional from energy firms to the oil market. Fuentes and Herrera (2020) focused on the links of 16 renewable energy companies and various volatility indicators associated with gold, stocks, and oil. The authors concluded low connectedness between renewable energy firms and implied-volatility of the oil prices, which naturally translate into better diversification opportunities. Even Geng et al. (2021) corroborated this diversification potential for 6 European renewable energy firms. Maitra et al. (2021) also exploited the approach of Diebold and Yilmaz (2012, 2014) to study the interdependence between oil and stock prices of 22 important logistics firms in the world. Their results revealed that oil acts as a net shocks receiver, and that its low interconnection with these companies is another interesting focus of international diversification. More recently, Chuliá et al. (2023) presented evidence for 219 emerging market energy firms using the LASSO-VAR approach introduced by Demirer et al. (2018). After isolating the incidence of common global factors using dynamic factor models, the authors demonstrated not only the significant connectedness between energy firms but also the relevance of common global factors attributable to fundamentals such as oil prices on system spillover.

2.2. Background on the link between natural gas and stock markets

Natural gas is one of the main energy sources worldwide and the cleanest compared to other fossil fuels such as oil and coal. According to Global Energy Trends (2024) and data obtained from the U.S. Energy Information Administration, global consumption of natural gas reached a record that exceeded 143,000 billion cubic feet (bcf) during 2022, equivalent to 23% of global energy consumption. Only in the United States, natural gas consumption represented 35.18% of its total energy consumption in 2022, slightly behind oil (38.73%) in the same period, and well above its consumption record during 2010 (25.83%)⁷. This systemic relevance makes the natural gas market a key player for global energy development as well as for investment decision-making.

In both developed and emerging countries, an extensive literature has addressed the spillover effects between natural gas and stock markets. Acaravci et al. (2012) studied this

⁷ For more details, visit the website of U.S Energy Information Administration at <https://www.eia.gov/international/data/world/total-energy/total-energy-consumption>

relationship using the stock indices for 15 European markets. Their findings demonstrated a close long-term relationship between both markets, which naturally creates an important channel of financial contagion. Gatfaoui (2016) and Ahmed (2018) found similar evidence for the stock markets of the United States and Qatar, respectively. On the other hand, Ling et al. (2019) investigated the risk transmission mechanisms between natural gas prices and stock markets in China and the United States. Using multivariate GARCH models, the authors verified that the spillover effects between these markets are dynamic, and that the unidirectional impact of natural gas only intensifies on the Chinese stock market in times of crisis, reducing its diversifying potential on portfolios. In fact, Mensi et al. (2021b) warn that the lower interconnection of natural gas with some BRICS stock markets such as China is an important source of international diversification. Furthermore, various studies on this matter corroborate that the link between natural gas prices and stock markets is much less intense than that experienced with oil (Gatfaoui, 2016; Geng et al., 2021; Mensi et al., 2021b). This advantageous position of natural gas in relation to oil provides concrete guidelines to design both more diversified investment strategies as well as more effective energy regulations in reducing dependence on fossil fuels and mitigating the economic-environmental consequences derived from climate change.

More recent literature has employed sectoral stock indices to explore the shocks transmission between natural gas and stock markets. Obviously, capturing the sectoral heterogeneity of financial contagion between both actors is the main goal of this part of the literature. For Naeem et al. (2020), this sectoral distinction is crucial since the energy uncertainty inherent to various fuels can increase risk in systemically relevant sectors and alter the effectiveness of energy regulations. In fact, Geng et al. (2020) provide a pioneering view of spillovers between natural gas prices and 10 sectors of the US stock market. The authors demonstrated the close interconnection between both markets, driven by the shocks that the natural gas market transmits to various sectors, mainly to the utilities sector. Dai and Zhu (2022) offer a similar analysis for various sectors of the Chinese stock market. The authors concluded that the natural gas market is a net shocks receiver, as are some sectors linked to metallurgy, agriculture and communications.

2.3. Recent advances on quantile connectedness between stock and fuels markets

The literature discussed in the previous sections corroborated the close link between stock markets and fuel markets such as oil and natural gas. However, two critical points emerge from it. A first critical aspect of these studies is that all of them have used mean-conditional connectedness approaches on samples based on aggregate stock indices or a limited number of companies. For this reason, a growing part of the research, motivated to provide a much more precise description of the connectedness between the stock and fuel markets beyond normal scenarios, has focused its efforts on studying the shocks transmission between them in extreme market conditions. The first studies on this subject used aggregate stock indices and demonstrated the existence of asymmetric spillovers between these markets. Du and He (2015) and Mensi et al. (2017) provided evidence of short- and long-term tail risk between oil prices and the US stock market using Value-at-Risk (VaR) and Variational Mode Decomposition (VMD), respectively. Naeem et al.

(2024), who analyzed the connectedness between the Chinese stock market and the prices of oil, natural gas and other financial assets, also highlight the asymmetry of spillovers and the diversifying role of the Chinese market. Other studies focused on stock, oil and natural gas markets also suggest the existence of more intense spillovers in extreme scenarios for both returns and volatility measures (Tiwari et al., 2018; Wang and Wu, 2018; Xu et al., 2019; Xie et al., 2021; Su et al., 2022). New investigations have adopted modern quantile connectedness approaches to through Quantile Autoregression Vector (QVAR) models. Saeed et al. (2021) presented a pioneering analysis of the shocks transmission between oil prices and various energy stock indices that demonstrated the greater connectedness intensity in bullish or bearish scenarios compared to normal market conditions. Hanif et al. (2024) also support this conclusion for the main oil-producers and consumers countries. Currently, work by Pham et al. (2023) is the only research based on firm-level approach. The authors use the quantile connectedness method introduced by Ando et al. (2022) to explore the shocks transmission between natural gas prices and the 10 largest utility companies in the United States. Its results highlight, on the one hand, the jump in total spillover from 75.4% in normal conditions to more than 86% in bullish and bearish scenarios, and on the other hand, the benefits that the natural gas market brings in terms of risk diversification and design of energy policies due to its low connection across quantiles.

A second critical aspect of previous studies, even for investigations based on quantile connectedness approaches, is that all of them have focused their analysis solely on the total spillover measure. Therefore, when they study a system composed of various types of markets, all of them have overlooked the role that specific-market connectedness (internal spillover) as well as the interaction between them (external spillovers) play on system's total interconnection (Feng et al., 2023). The studies carried out by Mensi et al. (2021b), who investigated the co-movements between the stock markets of BRICS countries and oil and natural gas prices, and Asadi et al. (2022), who did the same for the prices of oil, natural gas, coal, and the stock and exchange markets of the United States and China, are just some of the examples that describe the intense links between various markets solely based on total spillover. This is why various investigations warn that, to explore the shocks transmission between stock and energy markets, it is necessary to consider how the interdependence between the prices of different types of fuels contributes to the total link of the system (Su et al., 2022; Naeem et al., 2024). Recently, Feng et al. (2023) carried out pioneering research based on mean-conditional connectedness approach that addressed the study of co-movements between various stock markets (China and the G7 countries) and the prices of different energies (oil, coal, and natural gas). Using the spillover-decomposition approach introduced by Gabauer and Gupta (2018), the authors concluded that the system's total connectedness reached a figure of 57.19%, and of this, 10.22% is attributed to external spillover between the stock and fuel markets. According to the authors, this high magnitude of cross-market spillover creates a broad channel through which fuel markets can transmit important shocks to stock markets.

Our research is the first empirical work at firm-level that reconciles both critical points, providing new insights into the risks transmission between the prices of oil, natural gas and stocks of a broad set of energy firms. To do this, we innovatively combine the quantile connectedness approach of Ando et al. (2022) and spillovers-decomposition

method of Gabauer and Gupta (2018) to identify the global network structure and the magnitude of total, internal and external spillovers in bearish, normal and bullish scenarios.

3. Data

The prices data was extracted from Bloomberg, and all of them are expressed in US dollars. The sample selection obeys criteria of representativeness of both the period and the markets under analysis. First, the sample expands daily between January 3, 2006 and December 15, 2023. In total, there are 4,685 observations for each time series of fuel and stock prices. This appropriate length of time allows us to incorporate the incidence of systematically relevant events such as the Global Financial Crisis, the Sovereign Debt Crisis in Europe, the oil market crash between 2014 and 2015, the Covid-19 Pandemic and recent geopolitical conflicts between Russia-Ukraine and Israel-Gaza.

Second, to provide a more complete description of the global interconnections within the energy markets, the fuels and energy firms from those countries most relevant to the global energy consumption were selected. On the one hand, the fuel markets are represented by natural gas and crude oil, whose prices are measured through the National Balancing Point (NBP) and West Texas Intermediate (WTI) reference indices, respectively⁸. The selection of these fuels were not arbitrary. These markets can experience significant mutual contagion effects due to the cointegration relationships between their prices, a fact that can undoubtedly affect their links with stock markets (Acaravci et al., 2012; Batten et al., 2017). Indeed, Jadidzadeh and Serletis (2017) state that 45% of natural gas price changes are explained by oil shocks. In Addition, these markets were selected for their systemic relevance in global energy consumption. According to Global Energy Trends (2024), both oil and natural gas are two of the most important energy sources used in the world, and together they represented more than 53% of global energy consumption during 2022.

On the other hand, the stock markets are represented by 118 energy companies. These companies come from the following 10 countries: Canada, the United States, China, Japan, France, Germany, Italy, Norway, Spain and the United Kingdom⁹. These markets were selected due to their high participation in the global energy consumption as well as the data availability. According to the US Energy Information Administration, between 2018 and 2022, these 10 countries captured 46.16% and 51.36% of natural gas and oil global consumption, respectively. The United States leads the world consumption of both natural gas (22.99%) and oil (20.78%), followed by China (9.80% and 15.49% of natural gas and oil consumption) and Canada (3.17% and 2.56% of natural gas and oil consumption)¹⁰. Furthermore, the companies that make up the sample represent four sectors linked to the energy markets such as Utilities, Oil and Gas Producers, Oil and Gas Services and Renewable Energies, a fact that undoubtedly provides a more complete vision about the industry. Appendix 1 presents the details of the 118 energy companies in the sample

⁸ The NBP index is expressed in GBP/therm. The records were converted to dollars using the daily spot price between GBP and USD.

⁹ Other energy stock markets such as India, Russia, Iran, Indonesia and Saudi Arabia were not considered because there not complete records during the analysis period.

¹⁰ Other stock markets such as India, Russia, Iran, Indonesia and Saudi Arabia do not have complete data records for the analysis period.

Table 1. Statistical description for fuels and energy stock markets.

<i>Panel A. Fuel markets</i>									
Fuels markets	ID Code		Mean	S.D.	Min	Max	Skewness	Kurtosis	ADF test
Natural Gas	NGAS		0.000	4.87	-45.48	59.17	1.33	24.14	-16.54***
Oil	OIL		0.003	2.78	-60.17	24.89	-2.00	61.92	-15.66***
<i>Panel B. Energy stock markets at country-level</i>									
Countries	ID Code	Firms	Mean	S.D.	Min	Max	Skewness	Kurtosis	ADF test
Canada	CA	27	0.002	1.38	-24.84	11.46	-1.96	38.55	-17.11***
United States	US	43	0.010	1.52	-17.93	15.46	-0.62	18.88	-17.01***
China	CH	17	0.020	1.75	-10.46	9.35	-0.82	8.59	-15.39***
Japan	JP	6	-0.004	1.42	-14.81	10.75	-0.17	10.29	-17.09***
France	FR	1	-0.004	1.97	-23.96	16.71	-0.84	16.35	-15.81***
Germany	GE	2	-0.010	1.72	-15.96	14.79	-0.27	10.81	-16.62***
Italy	IT	6	-0.010	1.40	-18.75	10.47	-1.17	17.97	-17.16***
Norway	NW	4	0.010	2.28	-25.51	13.96	-0.51	10.73	-17.09***
Spain	SP	6	-0.001	1.34	-22.64	11.90	-1.71	30.95	-16.40***
United Kingdom	UK	6	0.010	1.07	-10.54	11.30	-0.23	13.38	-17.16***
<i>Panel C. Energy stock markets at sector-level</i>									
Aggregated Sector	ID Code	Firms	Mean	S.D.	Min	Max	Skewness	Kurtosis	ADF test
Utilities	UT	66	0.010	0.82	-10.19	7.84	-0.84	18.56	-16.22***
Oil and Gas Producers	OP	38	0.010	1.66	-24.99	12.25	-1.05	20.37	-16.53***
Oil and Gas Services	OS	12	-0.010	2.07	-35.71	13.73	-1.39	26.17	-15.95***
Renewables energies	RE	2	0.001	2.57	-19.32	24.83	0.54	11.62	-16.51***
<i>Panel D. Energy stock markets at country-sector-level</i>									
Country-sector	ID Code	Firms	Mean	S.D.	Min	Max	Skewness	Kurtosis	ADF test
Canada									
Utilities	CA.UT	10	0.010	1.07	-14.96	10.99	-1.20	31.38	-16.89***
Oil and Gas Producers	CA.OP	13	0.010	1.74	-30.94	11.90	-1.74	34.70	-16.93***
Oil and Gas Services	CA.OS	3	-0.050	2.87	-52.60	22.21	-1.28	30.88	-16.33***
Renewables energies	CA.RE	1	0.000	4.39	-37.16	49.66	0.94	17.53	-16.75***
United States									
Utilities	US.UT	22	0.010	1.22	-14.18	12.52	-0.21	18.66	-17.03***
Oil and Gas Producers	US.OP	16	0.010	2.23	-26.73	18.78	-0.51	13.75	-16.62***
Oil and Gas Services	US.OS	5	0.004	2.57	-36.78	18.97	-0.98	18.86	-15.63***
China									
Utilities	CH.UT	13	0.020	1.81	-10.66	9.39	-0.76	8.41	-15.45***
Oil and Gas Producers	CH.OP	3	0.030	2.00	-10.54	9.56	-0.58	6.93	-15.98***
Oil and Gas Services	CH.OS	1	0.010	2.44	-15.62	9.62	-0.05	6.83	-16.54***
Japan									
Utilities	JP.UT	5	-0.010	1.51	-15.19	11.08	-0.05	10.11	-16.91***
Renewables energies	JP.RE	1	0.002	2.43	-21.04	28.36	0.24	13.29	-16.67***
France									
Utilities	FR.UT	1	-0.004	1.97	-23.96	16.71	-0.84	16.35	-15.81***
Germany									
Utilities	GE.UT	2	-0.010	1.72	-15.96	14.79	-0.27	10.81	-16.62***
Italy									
Utilities	IT.UT	4	0.010	1.31	-20.18	9.87	-1.14	18.84	-16.84***
Oil and Gas Producers	IT.OP	1	-0.010	1.77	-23.39	15.71	-0.55	20.11	-18.07***
Oil and Gas Services	IT.OS	1	-0.070	3.41	-66.48	52.85	-3.04	80.86	-17.22***
Norway									
Oil and Gas Producers	NW.OP	2	0.003	2.46	-31.58	17.10	-0.65	14.42	-16.80***
Oil and Gas Services	NW.OS	2	0.010	2.55	-27.69	17.83	-0.36	10.07	-17.24***
Spain									
Utilities	SP.UT	5	0.002	1.36	-27.30	13.20	-2.44	49.20	-16.20***
Oil and Gas Producers	SP.OP	1	-0.010	2.01	-17.14	16.74	-0.14	10.51	-16.91***
United Kingdom									
Utilities	UK.UT	4	0.010	1.18	-9.25	13.69	-0.13	12.42	-17.04***
Oil and Gas Producers	UK.OP	2	0.010	1.43	-14.52	16.06	-0.19	12.70	-17.26***

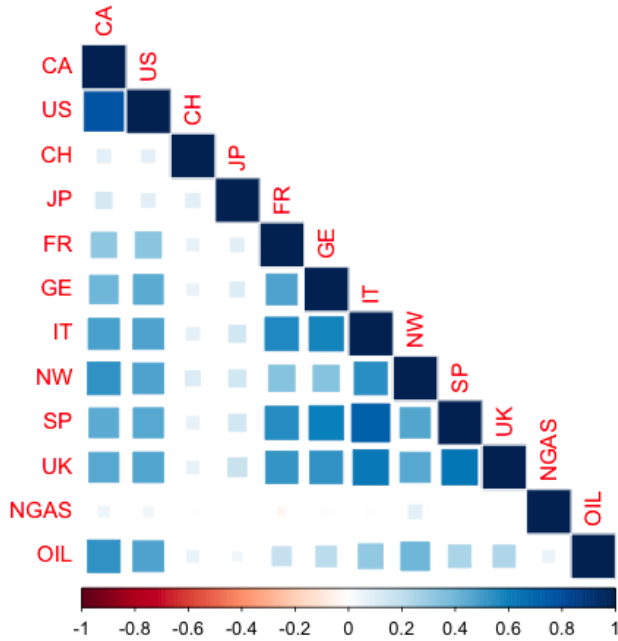
Notes: Statistics are in percentage points. Data correspond to the return for an equally-weighted portfolio for each country or sector. The sampled period extends from January 3, 2006, to December 15, 2023. ADF corresponds to the Augmented Dickey-Fuller unit root test. This test only considers the random walk specification. Superscripts ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Source: Authors.

Table 1 depicts the descriptive statistics for the daily returns of the fuel and energy stocks prices. It is important to mention that for the analysis at the country, sector and country-sector level, we compute the daily returns for an equally-weighted portfolio composed of firms belonging to a country, sector and specific-sector of the same country, respectively. Panel A displays the descriptive analysis for daily returns of natural gas and oil prices. The daily returns of these fuels fluctuated 0%, and of them, the natural gas prices showed greater volatility (4.87%) and a positive bias (1.33%) in comparison to oil, a fact that would have triggered by the unprecedented prices increases that natural gas has shown since the Russian invasion of Ukraine. Statistically, the fuels' returns presented excess kurtosis, and according to the ADF unit root test, both time series are stationary processes. Panel B shows the description of energy stock markets at the country-level. Stock returns exhibit averages close to 0% and left-skewed, while volatility shows a similar patterns across countries, oscillating between 1.07% (United Kingdom) and 2.28% (Norway). In all cases, the rejection of the ADF test reveals that all daily returns time series are stationary processes. At the sector and country-sector level, the statistical description is similar in terms of average returns and stationarity. Oil and gas services (OS) and renewable energies sectors presented the highest volatility records (Panel C). Energy firms from Italy (3.41%), Canada (2.87%) and the United States (2.57%) support this analysis for the Oil and Gas Services sector (Panel D). Appendix 2 presents the statistical description of the 118 energy companies that make up the sample.

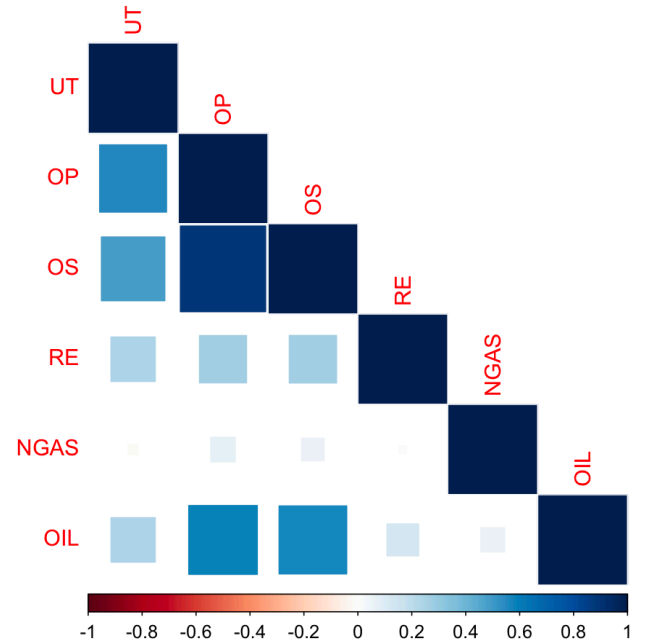
Figure 1 displays the Pearson correlation matrix between fuel and energy stock returns. Preliminarily, three facts merit more detailed discussion. First, energy stock markets are closely correlated. At the country-level, stands out the dependence between the US and Canadian energy stock markets, as well as between the European ones (Figure 1a). Naturally, this correlational scenario suggests that these markets are more susceptible to the shocks transmission and merit more rigorous monitoring by energy authorities. The energy stock markets of China and Japan are less correlated both with each other and with the rest of the countries and fuels. This would provide important spaces to diversify risk within energy stock portfolios and would contribute to mitigating the vulnerability of the energy industry in that region. At the level of sectors, country-sectors and firms, similar correlations are seen, although with a greater degree of heterogeneity. Second, oil and gas producers (OP) and oil and gas services (OS) are the most correlated sectors with each other, and after them, utilities sector (UT) also present high correlations (Figure 1b). However, the renewable energy sector offers the most important space to diversify risk, both in Canada and Japan (Figure 1c). Third, the natural gas and oil markets are virtually uncorrelated with each other, and only crude oil shows a significant positive correlation with energy stock market. This fact suggests that natural gas price shocks have a limited impact on both oil and energy firms stock prices. However, oil prices shocks may spread greater risks to energy firms, mainly those linked to oil and gas producers (OP) and oil and gas services (OS) in Canada, the United States and Italy. In this way, portfolios made up of energy and natural gas firms, as well as those built between crude oil and energy firms from Japan and China can be transformed into relevant investment alternatives to diversify risk within the energy industry.

Figure 1. Correlations matrix between energy stock and natural gas price returns.

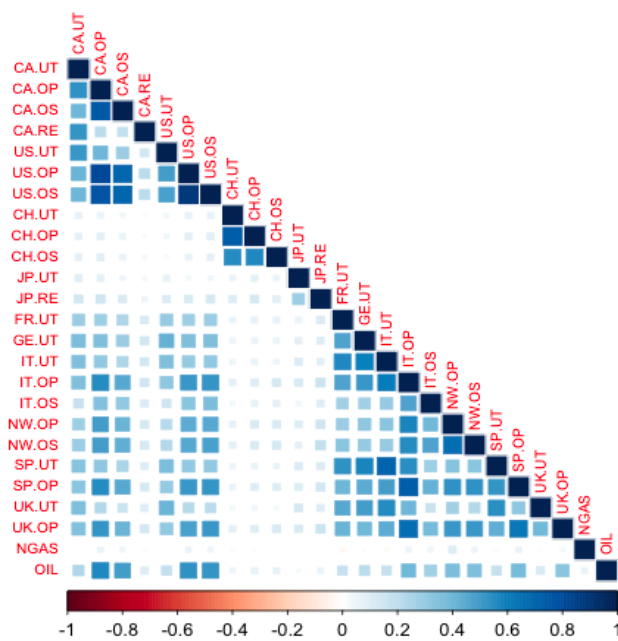
(a) At country-level



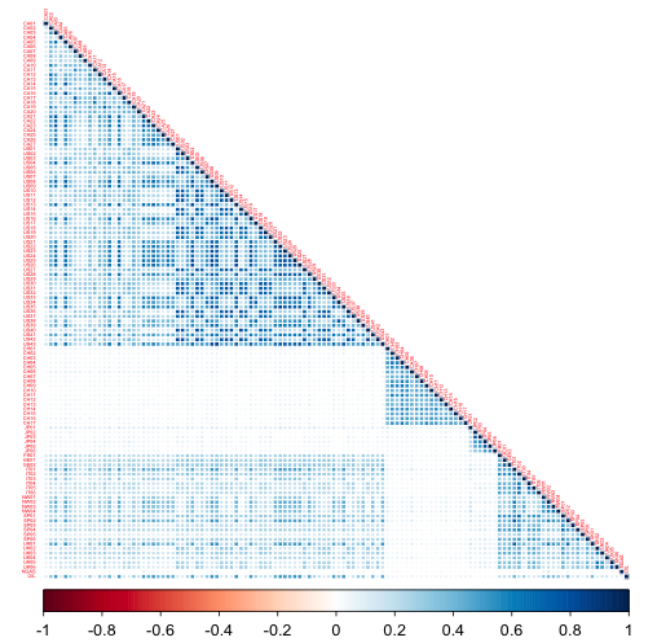
(b) At sector-level



(c) At country-sector-level



(d) At firm-level



Source: Authors elaboration.

4. Methodology

Here, we bring together the quantile connectedness approach proposed by Ando et al. (2022) and the bilateral spillover decomposition formulated by Gabauer and Gupta (2018). This combination allows us to obtain interconnectedness measures between the energy stock markets, oil and natural gas for different scenarios defined by specific quantiles of the returns distribution. Once these interconnections are estimated, they are decomposed to establish whether in each scenario of interest, the spillovers come from interactions within a specific-group or between cross-groups. All these analyzes are carried out at the level of countries, sectors and individual firms. Methodological details are provided below.

4.1. Quantile connectedness approach

In order to assess the interconnectedness between energy stock markets, oil and natural gas, we employ the quantile connectedness method introduced by Ando et al. (2022). This approach extends the traditional framework proposed by Diebold and Yilmaz (2012, 2014), incorporating a quantile vector autoregression model as baseline structure:

$$\mathbf{y}_t = \boldsymbol{\mu}(\tau) + \sum_{j=1}^p \boldsymbol{\Phi}_j(\tau) \mathbf{y}_{t-j} + \mathbf{u}_t(\tau), \quad (1)$$

where \mathbf{y}_t and \mathbf{y}_{t-j} are $k \times 1$ dimensional vectors that contain the endogenous variables in t and $t - j$, respectively. In addition, the quantile of interest $\tau \in [0,1]$, p is the autoregression order of the QVAR model, $\boldsymbol{\mu}(\tau)$ is a $k \times 1$ dimensional conditional mean vector, $\boldsymbol{\Phi}_j(\tau)$ is a $k \times k$ matrix that contains the coefficients of the QVAR system while $\mathbf{u}_t(\tau)$ is a $k \times 1$ dimensional vector with a variance–covariance matrix of dimension $k \times k$, denoted by $\boldsymbol{\Sigma}(\tau)$.

To describe the equation-by-equation quantile approach of the VAR system, we detail the single equation of (1) as:

$$y_{st} = \boldsymbol{\Phi}'_s(\tau) \mathbf{z}_t + u_{st}(\tau), \quad (2)$$

where $s = 1, 2, \dots, k$ and \mathbf{z}_t indicates the $(kp + 1) \times 1$ vector of all regressors including the intercept. The vector $\boldsymbol{\Phi}_s$ contains the corresponding autoregressive coefficients at τ -quantile and, naturally, the residuals $u_{st}(\tau)$ adhere to the conditional quantile restriction $Q_t(u_{st}(\tau) | \mathbf{z}_t) = 0$, where Q_t indicates the τ conditional quantile function of y_{st} .

According to Koenker and Hallock (2001), the autoregressive coefficients for a specific quantile τ can be estimate by solving the problem:

$$\min_{\boldsymbol{\Phi}'_s(\tau)} \sum_{t=1}^T (\tau - I[y_{st} \leq \boldsymbol{\Phi}'_s(\tau) \mathbf{z}_t]) (y_{st} - \boldsymbol{\Phi}'_s(\tau) \mathbf{z}_t), \quad (3)$$

where $I[\cdot]$ is the indicative function taking the value of 1 when $y_{st} \leq \boldsymbol{\Phi}'_s(\tau) \mathbf{z}_t$ and 0 otherwise, and T is the number of observations in the sample.

To derive the connectedness measures of Diebold and Yilmaz (2012, 2014) through Wold's Theorem within the QVAR framework, we can re-write the Equation (1) as an infinite moving average representation $QVMA(\infty)$ as follows:

$$\mathbf{y}_t = \boldsymbol{\mu}(\tau) + \sum_{i=0}^{\infty} \boldsymbol{\psi}_i(\tau) \mathbf{u}_{t-i}, \quad (4)$$

where the $k \times k$ dimensional coefficients matrix, denoted by $\boldsymbol{\psi}_i(\tau)$, is defined as:

$$\boldsymbol{\psi}_i(\tau) = \begin{cases} 0 & , i < 0 \\ \mathbf{I}_k & , i = 0 \\ \boldsymbol{\Phi}_1 \boldsymbol{\psi}_{i-1}(\tau) + \boldsymbol{\Phi}_2 \boldsymbol{\psi}_{i-2}(\tau) + \dots + \boldsymbol{\Phi}_p \boldsymbol{\psi}_{i-p}(\tau) & , i > 0 \end{cases} \quad (5)$$

According to Diebold and Yilmaz (2012), the moving average representation is relevant to understand system dynamics and connectedness statistics. To achieve order-invariant variance decompositions of the QVAR system, these connectedness measures employ the methodological framework proposed by Koop et al. (1996) and Pesaran and Shin (1998), hereinafter KPPS. Therefore, for $H = 1, 2, \dots$, we denote the KPPS H -step-ahead forecast error variance decomposition as:

$$\theta_{ij}^g(H) = \frac{\Sigma(\tau)_{ii}^{-1} \sum_{h=0}^{H-1} (\mathbf{e}_i' \boldsymbol{\psi}_h(\tau) \Sigma(\tau) \mathbf{e}_j)^2}{\sum_{h=0}^{H-1} (\mathbf{e}_i' \boldsymbol{\psi}_h(\tau) \Sigma(\tau) \boldsymbol{\psi}_h(\tau) \mathbf{e}_i)}, \quad (6)$$

where $\Sigma(\tau)_{ii}$ is the standard deviation of the error of the i -th equation in the quantile τ , and \mathbf{e}_i is a selection vector with value one at the i -th element and zero otherwise. As the sum of the elements of each row in Equation (6) is not equal to 1 ($\sum_{j=1}^k \theta_{ij}^g(H) \neq 1$), in order to get a unit sum of each row of the variance decomposition matrix, the following normalization must be done for each entry:

$$\tilde{\theta}_{ij}^g(H) = \frac{\theta_{ij}^g(H)}{\sum_{j=1}^k \theta_{ij}^g(H)}, \quad (7)$$

where by construction $\sum_{j=1}^k \tilde{\theta}_{ij}^g(H) = 1$ and $\sum_{i,j=1}^k \tilde{\theta}_{ij}^g(H) = k$. Equation (7) thus constitutes a natural measure of the pairwise directional spillover from variable j to variable i . Next, the total directional spillover received by variable i from all other variables j is:

$$S_{i \leftarrow \circ}^g(H) = \sum_{\substack{j=1 \\ j \neq i}}^k \tilde{\theta}_{ij}^g(H), \quad (8)$$

Similarly, the total directional spillover transmitted by variable i to other variables j is:

$$S_{\circ \leftarrow i}^g(H) = \sum_{\substack{j=1 \\ j \neq i}}^k \tilde{\theta}_{ji}^g(H). \quad (9)$$

The net spillover from variable i to the remaining variables j is:

$$S_i^g(H) = S_{\circ \leftarrow i}^g(H) - S_{i \leftarrow \circ}^g(H). \quad (10)$$

This measure of net connectedness shows the dynamics between the shocks transmitted and received by a market within the QVAR system. Finally, using the KPSS variance decomposition, the adjusted total spillover or system-wide connectedness of Chatziantoniou and Gabauer (2021) and Gabauer (2021) which ranges between [0,1], can be represented by:

$$S^g(H) = \frac{\sum_{i,j=1}^k \tilde{\theta}_{ij}^g(H)}{k-1}. \quad (11)$$

This spillover measure quantifies the contribution of the shocks of the k variables to the forecast error variance (Diebold and Yilmaz, 2009). Usually, this measure is used as a proxy for market risk, therefore, in our case, a higher $S^g(H)$ shows a higher degree of interconnectedness between the markets in the QVAR system.

4.2. Quantile connectedness decomposition

According to Gabauer and Gupta (2018), the total net spillover indicated in (10) can be decomposed bilaterally into internal and external spillovers. The main advantage of this decomposition is that it allows to establish whether the system connectedness comprised of k variables come from a specific-group or cross-groups. Considering a q -groups system (q -types of markets), the decomposition is defined as:

$$\Theta(H) = \tilde{\theta}_{ij}^g(H) = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1q} \\ c_{21} & c_{22} & \cdots & c_{2q} \\ \vdots & \vdots & \ddots & \vdots \\ c_{q1} & c_{q2} & \cdots & c_{qq} \end{bmatrix} \quad (12)$$

where the element c_{ii} represents the internal or a specific-group spillover of the market i and c_{ij} indicates the external or cross-groups spillover from the type j market to type I market. Next, $c_{ii} = 0$ is set to zero, and the internal and external spillovers are computed as:

$$TO_{ij} = \sum_{n=1}^q c_{ij,nm} \times FROM_{ij} = \sum_{m=1}^q c_{ji,nm} \quad (13)$$

$$NET_{ij} = TO_{ij} - FROM_{ij} \times NI_{ij} = \sum_{n=1}^q \sum_{m=1}^q c_{ij,nm} - \sum_{n=1}^q \sum_{m=1}^q c_{ji,nm} \quad (14)$$

where TO_{ij} is the total specific-group (internal) connectedness to others, $FROM_{ij}$ is the total specific-group connectedness from others, NET_{ij} is the net total specific-group connectedness, and NI_{ij} is the net cross-group (external) connectedness. Then, the specific-group and cross-group total connectedness indices, denoted as $S^\kappa(H)$ and $S^x(H)$, respectively, are calculates as follow:

$$S^\kappa(H) = \frac{\sum_{i \in \rho} 1 - \tilde{\theta}_{ii}^g(H)}{k-1} S^x(H) = S^g(H) - \sum_{i=1}^q S_i^x(H), \quad (15)$$

where ρ is a set of all variables associated with the type κ market. In our case, we will consider two groups: (a) energy stock markets, and (b) fuel markets.

5. Empirical results

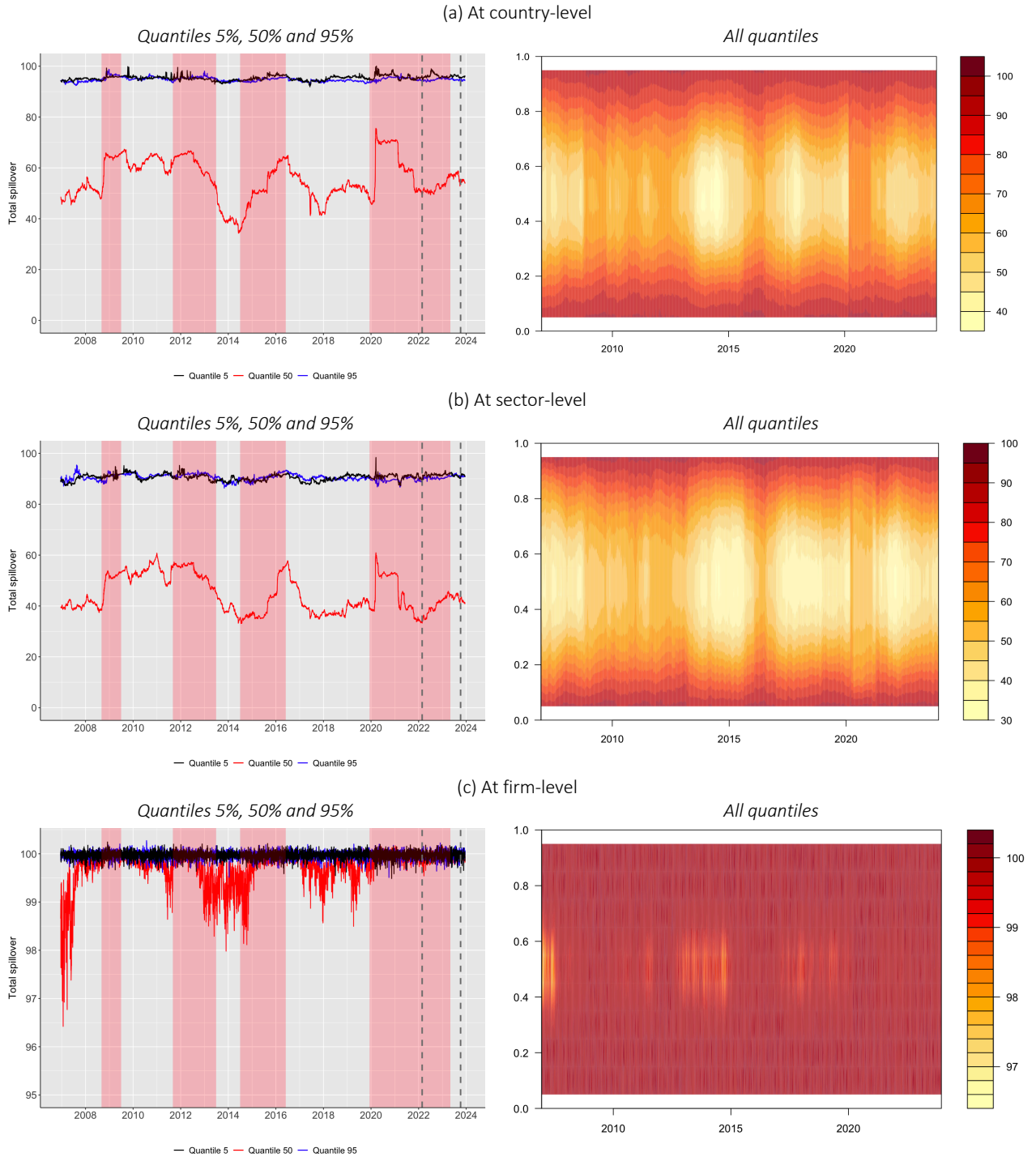
5.1. *Quantile connectedness between energy markets and fuels*

Here, we analyze the spillovers dynamics between fuel and energy stock markets across time and different quantiles of returns' distribution. Methodologically, we employ the quantile connectedness approach introduced by Ando et al. (2022). According to the Bayesian Information Criterion (BIC), the estimation results were based on a QVAR(1) specification. Additionally, we consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window for the connectedness statistics computation.

Figure 2 displays the connectedness between fuel and energy stock markets at different quantiles of the returns' distribution. Figure 2a presents country-level spillovers for both specific quantiles (left) and all quantiles (right). We observe three facts of special interest for investment decisions and the design of energy regulations. First, the interconnections between fuel and energy stock markets vary both over time and across different quantiles of the return distribution. The intensity of the spillovers changes dynamically within a range that fluctuates between 40% and 97%. Second, there is an evident connectedness asymmetry between extreme returns and average returns scenarios. In bullish (95% quantile) and bearish (5% quantile) scenarios, the total spillover ranged around 90%, a situation that contrasts with figures around 50% for quantiles close to the average. This configuration suggests that in scenarios characterized by returns close to 0% there is greater margin for risk diversification, while bullish and bearish scenarios describe greater vulnerability of global energy markets due to a more intense shocks transmission between fuel and energy stock markets. Undoubtedly, the greater magnitude of spillovers in extreme returns scenarios reveals that the strong dependence between energy firms and fuels such as natural gas and crude oil is a key factor that hinders the energy transition process and the effectiveness of policies aimed at stimulating clean energy investment. Third, crisis periods experienced spillovers of greater intensity along all quantiles of the return distribution. Periods such as the Global Financial Crisis, the Sovereign Debt Crisis in Europe, the Oil Crash and the Covid-19 Pandemic generated a systematic increase in the connectedness measures, mainly in the quantiles close to the average return, in which spillovers increased from 50% to levels above 64%.

Figure 2b presents the sector-level connectedness measures for both specific quantiles (left) and all quantiles (right) of the returns distribution. Utilities (UT), oil and gas producers (OP), oil and gas services (OS) and renewable energies (RE) are the sectors that compose this system, along with the natural gas and crude oil markets. Each sector is represented by the daily returns of an equally-weighted portfolio composed of the firms classified in each economic sector. The results are similar to those previously presented in the analysis at country-level (Figure 2a). However, the magnitude of the spillovers oscillated in a lower range (between 30% and 90%), particularly for the interconnections of the intermediate quantiles. In this way, the lower intensity connectedness measures observed between the fuel and energy sectors reveal that the diversification possibilities for portfolios that contemplate different energy sectors are more advantageous than those based on different countries.

Figure 2. Total spillover between energy stock markets and fuel markets.



Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. Global Financial Crisis considers the period between September 01, 2008 and June 30, 2009; the European Government Debt Crisis considers the period between September 03, 2011 and June 30, 2013; the Oil Crash period between July 01, 2014 and June 01, 2016; and the Covid-19 Pandemic considers the period between December 09, 2019 and May 05, 2023. The segmented gray line indicates the beginning of the Russian Invasion of Ukraine (February 24, 2022) and the Israel-Gaza War (October 7, 2023). Source: Authors.

Figure 2c presents the spillovers for the system comprised by the 118 energy firms and fuels for the quantiles of interest (left) and all quantiles (right) of the return distribution. It is evident that the interactions between energy firms and fuels show spillovers more intense, which normally fluctuate between 95% and 100% throughout all quantiles of returns. Only in some periods and quantiles the links were slightly smaller, suggesting limited benefits for diversifying risk among these actors. Naturally, the high intensity of interconnections between fuel and energy firms suggests that firms face high-relative costs to face the ongoing energy transition process and reduce their dependence from fossil fuels.

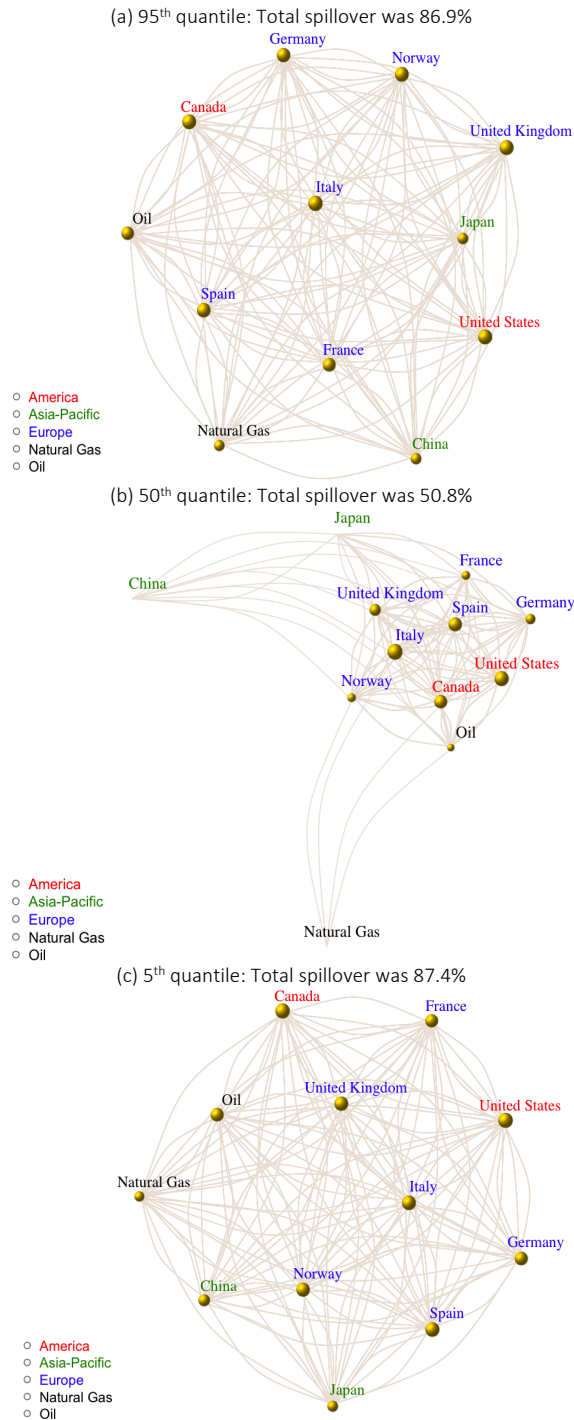
5.2. Network analysis

This section shows the network analysis between the fuel and energy stock markets as a way to describe the structure and intensity of the interconnections between these actors. Figure 3 presents the country-level networks for the 95% (bullish scenario), 50% (average scenario), and 5% (bearish scenario) quantiles of the daily return distribution. Figure 3a shows the spillovers network for the 95% quantile, in which case the complete system reached a total spillover of 86.9%. In this high-returns scenario, the energy stock markets are closely interconnected with crude oil and natural gas markets. The dense structure of the network as well as the transmission of high intensity shocks between these actors create a particular context for risks contagion in energy markets, and naturally, greater difficulties for portfolio allocation. Energy stock markets of North America and Europe transmit the most significant spillovers within the network in bullish scenarios, while the energy stock markets of Japan and China together to oil and natural gas are located in the most external areas of the network, where these markets are less vulnerable to the shocks transmitted by other system's actors.

Figure 3b presents the network for the 50% quantile of daily returns, considered as an average scenario. When the returns of the fuel and energy stock markets are around 0%, the system generates a total spillover of 50.8%. In this quantile, the network structure provides three important findings that merit a special analysis. First, the energy stock markets of Italy, the United States, Spain, Canada and the United Kingdom are located at the center of the global network, position from which they transmit the most relevant shocks within the system. Other energy stock markets such as Germany, Norway and France are less connected and have a lower capacity to spread risks. The strong interaction between these energy stock markets constitutes the most relevant source of risks transmission within the global network, and its greater vulnerability to system shocks would force energy authorities to supervise them with special attention. Second, the energy stock markets of Japan and China are located in the outer zones of the network and, given their lower exposure to system shocks, offer important advantages for the risk diversification of energy portfolios. Third, fuel markets are also located in the external areas of the network, suggesting that much of the system's spillover is due to interactions within energy stock markets. Oil is the fuel that transmits the greatest spillovers, while natural gas has a lower transmission capacity, which is mainly focused on the energy stock markets of Norway, Canada and Italy. In terms of energy policy design, there is no doubt that energy stock markets that are less vulnerable to fuel shocks can face a less costly

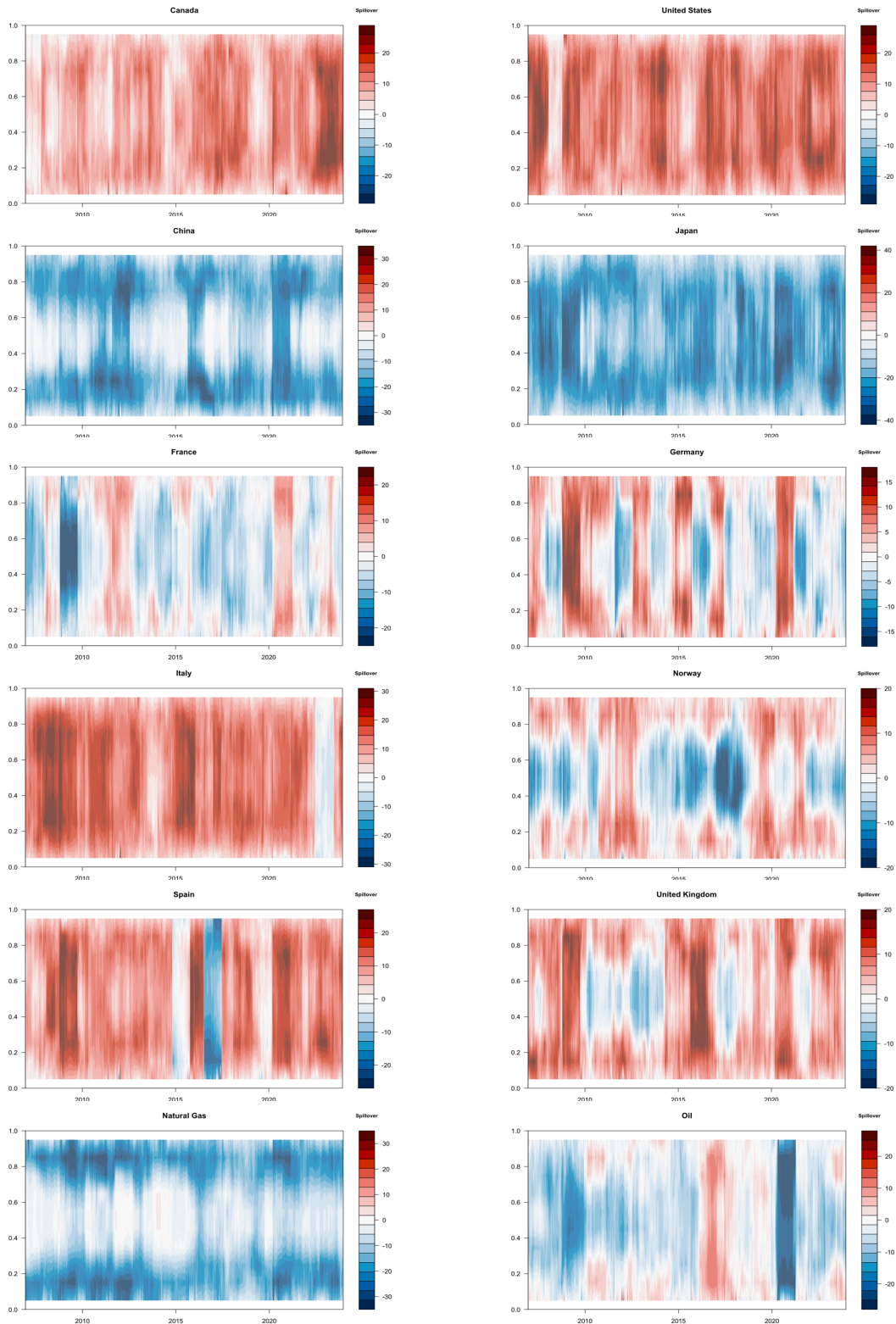
energy transition towards renewable sources compared to those that are more interconnected with them.

Figure 3. Spillover network across different quantiles: country-level.



Note: Spillover networks were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. Source: Authors.

Figure 4. Net spillover at country-level across quantiles and time.



Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. Source: Authors.

Figure 3c displays the network for the 5% quantile, defined as a bearish or negative returns scenario. The network structure is similar to that indicated by Figure 3a, fact that suggests a certain degree of symmetry of the spillovers between extreme quantiles of the return distribution. Certainly, the system's total spillover reached a figure of 87.4%, and once again, the North American and European energy stock markets are located at the center of the network as the main actors in the shocks transmission. On the other hand, the energy stock markets of Japan and China, joint to oil and natural gas markets, show lower vulnerability to system shocks and greater advantages for portfolio diversification.

In any case, a common aspect to all networks presented in Figure 3 is the active and systematic participation of the energy stock markets of North America (United States, Canada) and Europe (Italy, Spain, United Kingdom) as relevant actors in the shocks transmission through the different quantiles of the return distribution. In fact, Figure 4 indicates these markets as the main net transmitters of the system. Undoubtedly, the more intense interconnections between these energy stock markets impose important limitations on the energy transition process and the effectiveness of policies aimed at cushioning the effects of climate change in developed countries. The energy stock markets of France, Germany and Norway play a secondary role on system's connectedness. The shock transmission pattern of these markets is mixed and changes towards states of net transmitters in periods of strong financial tensions such as the Sovereign Debt Crisis in Europe and the Covid-19 Pandemic. On the other hand, Japan and China stand out for being the main net receivers of the system and, naturally, for the important advantages for risk diversification offered by their less vulnerable and connected positions within the global network. Regarding fuels, natural gas acts as a net receiver mainly at extreme quantiles, while crude oil is a mixed transmission market over time and different quantiles.

Figure 5 presents the networks between the fuel and energy stock markets at the level of sectors and country-sectors for the 95%, 50% and 5% quantiles of the return distribution. A common aspect that was observed in all quantiles under analysis is the greater system's total spillover at country-sector level in comparison to sector approach. At the sector-level, the total spillover indices were 75.4%, 37.2% and 75.5% for the 95%, 50% and 5% quantiles of the return distribution, figures that increased to 94.3%, 65.0% and 94.8% for the same quantiles under the analysis at the country-sector level. The greater intensity of system spillovers at the country-sector level reveals that sectoral diversification in energy markets is more beneficial between countries than within the same country.

Figure 5a (left) shows the global network for the 95% quantile of the return distribution. In this scenario, the system's total spillover is 75.4% and is mainly driven by the higher connectedness in the Oil and Gas Producers (OP) and Oil and Gas Services (OS) sectors. These sectors are located in the center of the global network, where we identify the sectoral markets of the United States, Canada, Spain and the United Kingdom as the most relevant in the shocks transmission (right). Oil once again stands out as the fuel that spreads spillovers of greater intensity in relation to natural gas. On the other hand, Chinese and Japanese firms in those sectors, together with natural gas market, are located in the peripheral areas of the network, and as they are less vulnerable to the shocks transmission, they become relevant actors to diversify risk in the energy industry. Figure 5c (left) presents a similar connectedness structure for bearish scenarios (Pham et al., 2023). The total spillover reached a figure of 75.5%, driven by the Oil and Gas Producers (OP) and Oil

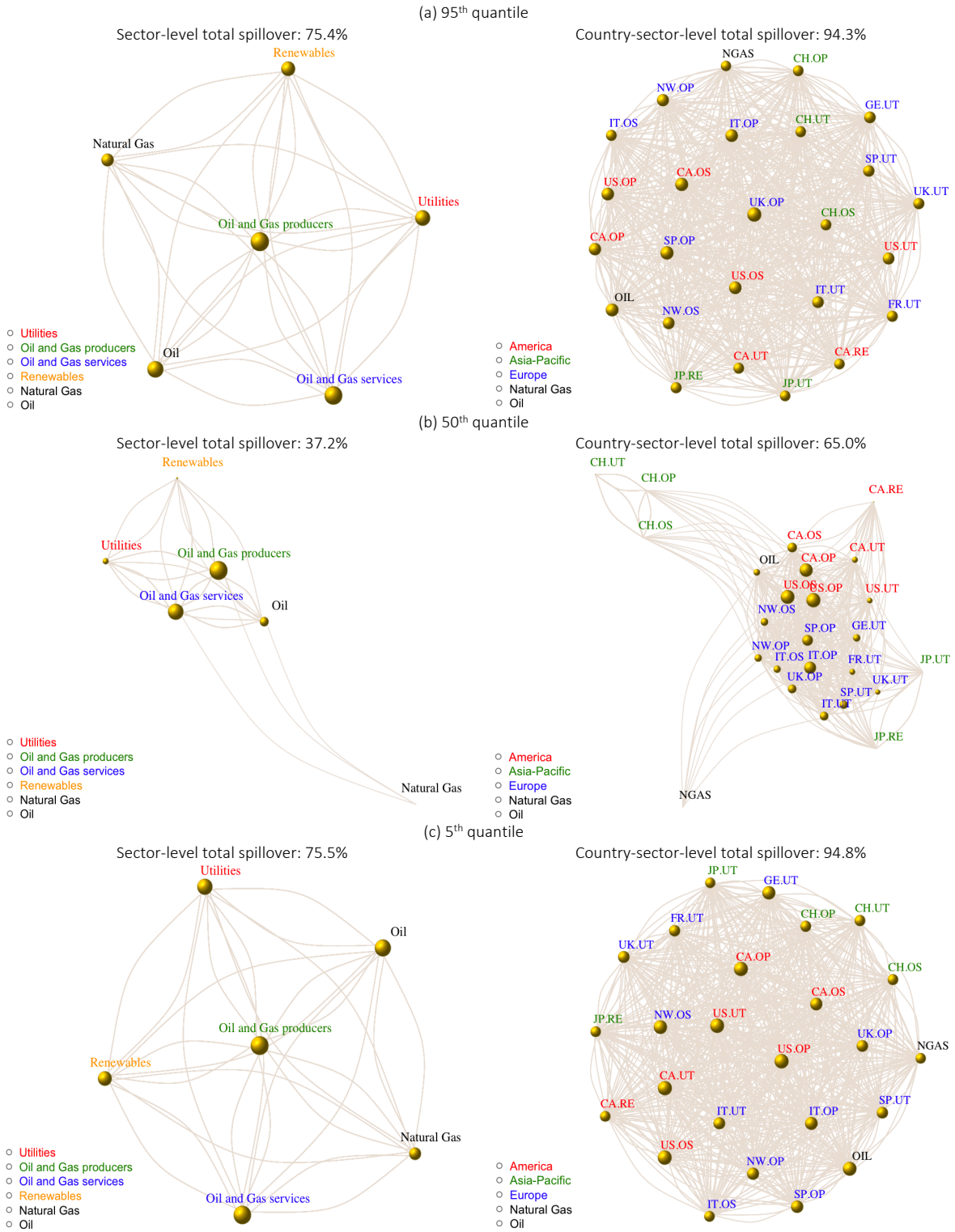
and Gas Services (OS) sectors of the United States and Canada as the main shocks transmitters (right). Along with them, oil is the fossil fuel that spread more risks within the energy global network. Renewable energy (RE) sector as well as natural gas are found in the peripheral areas of the network, favoring the diversification of energy portfolios.

Figure 5b (left) depicts the global energy network for the 50% quantile of returns. The Oil and Gas Producers (OP) and Oil and Gas Services (OS) sectors are the most important actors in the shocks transmission within network, mainly in the markets of the United States, Canada, Spain and Italy, where oil is the most linked fuel to them. Despite this, the total spillover between the oil, natural gas and energy stock markets in this average scenario was lower and reached 37.2%. On the other hand, renewable energy (RE) and utilities (UT) sectors, mainly from China and Japan, along with natural gas, recorded low spillovers that cushion the full system's total connectedness at sector-level and facilitate risk diversification.

Now, we discuss some common aspects present across all quantiles and that have relevant implications for the design of energy regulations as well as for investment decisions in this industry. First, in both extreme and intermediate return scenarios, it is evident that the Oil and Gas Producers (OP) and Oil and Gas Services (OS) sectors are the main net shocks transmitters of the energy system (Figure 6). The strong interconnections of these sectors within the global network, mainly with the oil market, make more difficult the energy transition process in the developed markets of North America and Europe. Second, renewable energy sector are net shock receivers and their lower connection with other network's actors opens important spaces to diversify energy portfolios. Even the lower connectedness between natural gas and oil, and their partial disconnection in intermediate quantiles can stimulate the development of energy policies aimed at reducing their use.

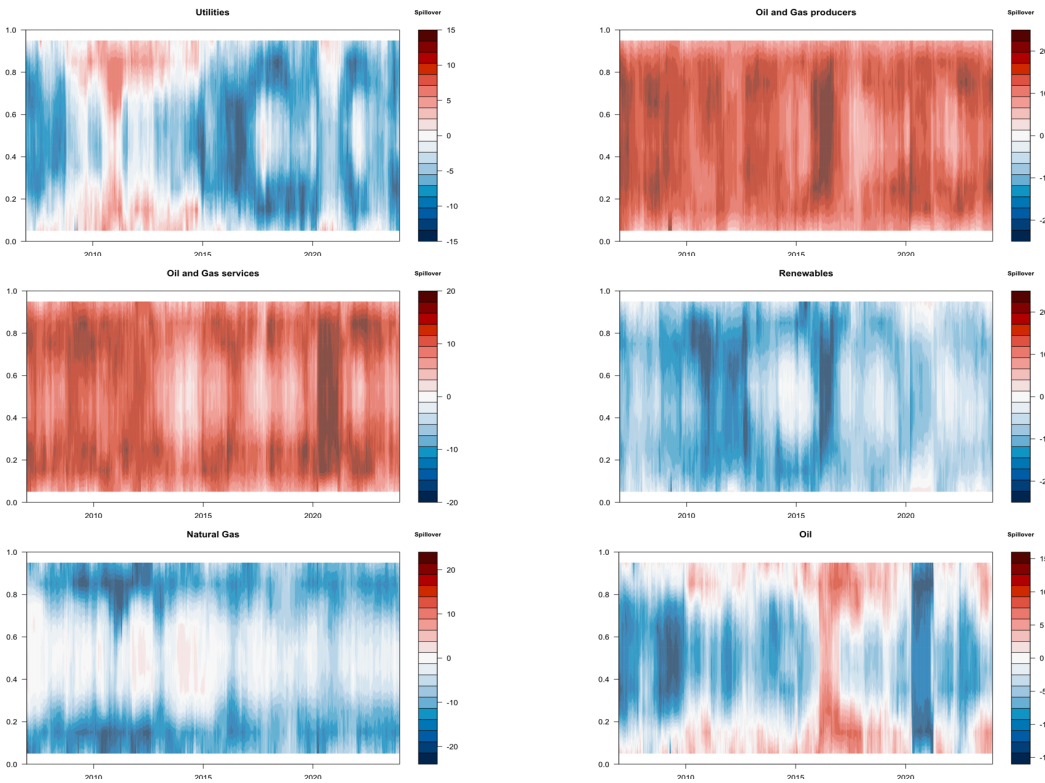
Figure 7 presents the networks build from the interactions between 118 energy firms and fuel markets. On the one hand, the extreme quantiles of returns distribution show similar structures. The bullish (95% quantile) and bearish (5% quantile) return scenarios present a total spillover of 99.1%. The central zones of both networks are dominated by the influence of US energy firms, while in the peripheral zones Canadian (95% quantile) and Chinese (5% quantile) energy firms offer the best prospects for risk diversification. On the other hand, in average return scenarios (50% quantile), the total spillover reaches a record of 98.9%. Although the system's connectedness is not significantly altered across quantiles, the networks' structures show different patterns between average and extreme scenarios. The US energy firms continue to be the most connected actors to the global network as well as the transmitters of the most intense shocks. However, Chinese energy firms offer the best diversification benefits in the industry by being less connected within the network and less vulnerable to system shocks.

Figure 5. Spillover network across different quantiles: sector-level.



Note: Spillover networks were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. Source: Authors.

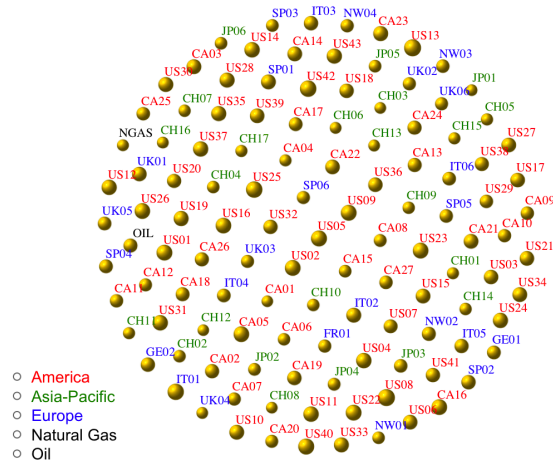
Figure 6. Net spillover at sector-level across quantiles and time.



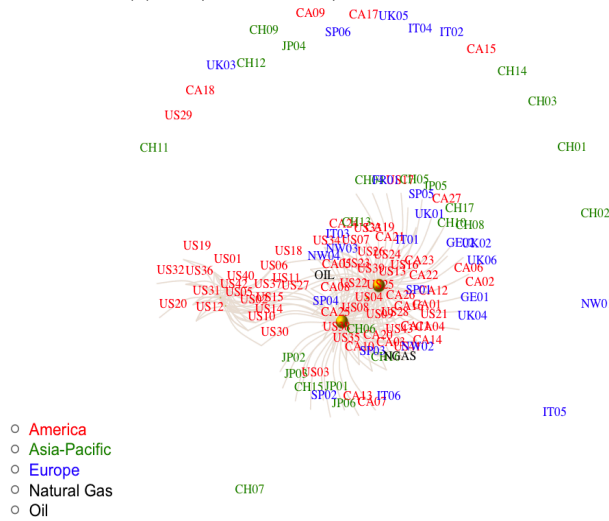
Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. Source: Authors.

Figure 7. Spillover network across different quantiles: firm-level.

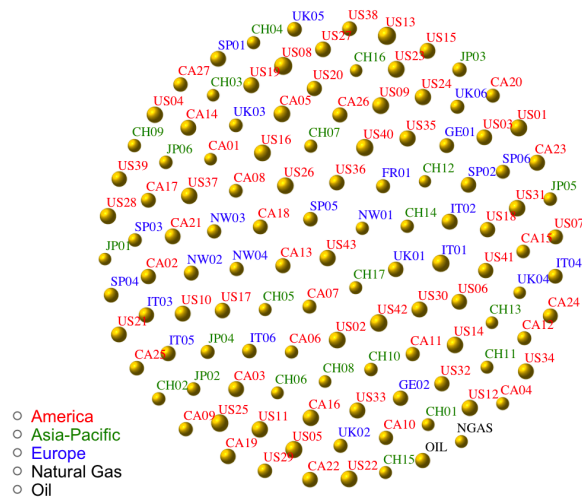
(a) 95th quantile: Total spillover was 99.1%



(b) 50th quantile: Total spillover was 98.9%



(c) 5th quantile: Total spillover was 99.1%



Note: Spillover networks were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. Source: Authors.

5.3. Spillover decomposition, risk diversification and transmission channels

This section provides a complete description of the connectedness magnitude, identifying the actors that contribute most to the shocks transmission as well as those that, because they are less vulnerable, provide important advantages for the risk diversification of energy portfolios. To do this, we disaggregate the information from a perspective at the level of countries, sectors, country-sectors to one at the firms-level, combining the spillover decomposition approach proposed by Gabauer and Gupta (2018) and the quantile connectedness method introduced by Ando et al. (2022) for each quantile of interest of the return distribution.

Table 2 shows the connectedness measures between fuel and energy stock markets at country-level. For each interest quantile of the return distribution, the markets are organized decreasingly according to the total spillover transmitted to others. For the extreme quantiles we observe similar connectedness statistics (Pham et al., 2023; Feng et al., 2023), where two aspects stand out for a deeper discussion. First, an interesting fact about the connectedness symmetry in extreme scenarios is the relevance of internal and external spillovers. On the one hand, in bullish scenarios (95% quantile), the system's total connectedness was 86.9%, where 62.1% come from the specific-market spillover and 24.8% corresponds to the cross-market spillover. On the other hand, in bearish scenarios (5% quantile), the total spillover of the entire system was 87.4%, and of this record the specific-market and cross-market spillovers were 62.5% and 24.9%, respectively. This finding demonstrates that an important part of the total connectedness between fuel and energy stock markets (country-level) comes from the interconnections developed within each specific market (Feng et al., 2023). Despite this, just over a quarter of all total connectedness is also due to the interaction between them, which suggests that bidirectionally fuel markets can transmit relevant shocks to energy stock markets and thereby reduce not only the benefits of international diversification but also impose higher costs on the energy transition process that various countries are undertaking to reduce their dependence on fossil energies.

Second, in both extreme quantiles, the markets most and least vulnerable to the shocks transmission of the system are identified. The energy stock markets of North America (United States, Canada) and Europe (United Kingdom, Italy, Spain, France, Germany, Norway) are the main shocks transmitters of the system in both bullish and bearish scenarios. Evidently, these markets impose higher diversification costs on investment decisions as well as on energy regulations aimed at strengthening the energy transition towards renewable sources. The energy stock markets of China and Japan are the least vulnerable to shocks transmitted by other actors in the global network, thereby facilitating the diversification of energy portfolios. This classification is also seen in the contribution of these markets to specific-market spillover. This lower connectedness is also shared by the oil and natural gas markets, which only have a greater impact on cross-market spillover to others.

Table 2. Spillover decomposition between energy stock and fuel markets: country-level.

Markets	Total spillover index			Specific-market spillover (internal)			Cross-market spillover (external)		
	To other	From others	Net	To other	From others	Net	To other	From others	Net
<i>A. 95th quantile of return's distribution</i>									
Italy	94.2	87.7	6.6	78.6	74.4	4.3	15.6	13.3	2.3
United States	93.5	87.5	6.1	76.3	72.6	3.7	17.2	14.9	2.4
United Kingdom	92.9	87.7	5.2	77.5	74.2	3.3	15.4	13.5	1.9
Canada	91.9	87.5	4.5	74.8	72.3	2.5	17.1	15.1	2.0
Spain	91.5	87.3	4.2	76.6	74.3	2.3	14.9	13.0	1.9
Germany	91.2	87.3	3.9	75.8	73.8	2.0	15.5	13.5	1.9
Norway	91.2	87.4	3.8	74.2	72.4	1.7	17.0	14.9	2.1
France	88.0	87.0	1.1	73.3	73.8	-0.5	14.8	13.2	1.6
Oil	84.9	86.7	-1.8	8.1	7.0	1.1	76.8	79.7	-2.9
Japan	76.9	86.1	-9.3	62.3	71.5	-9.2	14.5	14.6	-0.1
China	75.1	85.3	-10.2	60.5	70.5	-10.0	14.6	14.8	-0.2
Natural Gas	71.0	85.0	-14.0	7.0	8.1	-1.1	64.0	76.9	-12.9
System average	86.9	86.9	0.0	62.1	62.1	0.0	24.8	24.8	0.0
<i>B. 50th quantile of return's distribution</i>									
Markets	To other	From others	Net	To other	From others	Net	To other	From others	Net
Italy	84.3	68.2	16.1	78.8	64.7	14.2	5.5	3.6	1.9
United States	80.8	65.1	15.7	66.8	54.9	11.9	14.0	10.1	3.9
Spain	76.5	65.9	10.6	72.7	63.3	9.4	3.8	2.6	1.2
Canada	75.5	64.3	11.2	60.4	53.4	7.0	15.0	10.9	4.2
United Kingdom	65.1	62.9	2.2	61.8	60.1	1.7	3.4	2.9	0.5
Germany	58.0	59.0	-1.0	54.7	56.5	-1.8	3.3	2.5	0.8
Norway	53.4	59.9	-6.5	44.6	51.9	-7.3	8.8	8.0	0.8
France	51.6	56.8	-5.2	48.7	54.5	-5.8	2.9	2.3	0.6
Oil	42.6	50.7	-8.2	1.3	0.8	0.5	41.3	49.9	-8.7
Japan	8.7	32.0	-23.3	7.5	30.1	-22.6	1.2	1.9	-0.7
China	6.8	14.2	-7.4	5.4	12.1	-6.7	1.4	2.1	-0.7
Natural Gas	6.4	10.7	-4.3	0.8	1.3	-0.5	5.6	9.4	-3.8
System average	50.8	50.8	0.0	42.0	42.0	0.0	8.8	8.8	0.0
<i>C. 5th quantile of return's distribution</i>									
Markets	To other	From others	Net	To other	From others	Net	To other	From others	Net
United States	95.4	87.8	7.5	78.2	73.1	5.1	17.2	14.8	2.4
Canada	94.3	88.0	6.3	76.9	73.0	3.9	17.4	14.9	2.4
Italy	94.0	88.5	5.5	78.3	74.9	3.5	15.7	13.6	2.0
United Kingdom	92.7	88.0	4.8	77.1	74.3	2.8	15.6	13.6	2.0
Spain	91.3	88.1	3.3	76.4	74.6	1.8	14.9	13.4	1.5
Germany	90.5	87.7	2.9	75.3	74.0	1.3	15.2	13.7	1.6
Norway	90.0	87.9	2.0	73.5	73.2	0.3	16.5	14.7	1.8
France	88.2	87.8	0.4	73.3	74.2	-0.9	14.9	13.5	1.3
Oil	87.8	87.2	0.6	8.1	6.6	1.4	79.7	80.5	-0.8
China	79.2	86.3	-7.1	64.0	71.5	-7.5	15.2	14.8	0.4
Japan	76.9	87.2	-10.4	62.6	72.8	-10.2	14.3	14.5	-0.1
Natural Gas	68.5	84.5	-15.9	6.6	8.1	-1.4	61.9	76.4	-14.5
System average	87.4	87.4	0.0	62.5	62.5	0.0	24.9	24.9	0.0

Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. We use a classification of $q = 2$ groups or markets, defined as fuel (natural gas and oil) and energy stock markets. In each panel, markets are presented according to decreasing spillover to others. Source: Authors.

In average return scenarios (50% quantile), the energy stock markets of North America (United States, Canada) and Europe (United Kingdom, Italy, Spain, France, Germany, Norway) continue to be the main protagonists in the shocks transmission, while the Asian energy stock markets (Japan, China) as well as the fuel markets (crude oil and natural gas) are the least vulnerable actors within the energy system. However, the total spillover associated to this quantile is lower than what is observed at the extremes of the returns distribution (Pham et al., 2023; Feng et al., 2023). The system's total connectedness

reached 50.8% for this quantile, and of it 42.0% corresponds to specific-market spillover and only 8.8% to cross-market spillover. Practically, in normal scenarios, almost a fifth of total connectedness is due to the interaction between the fuel and energy stock markets. The smaller bidirectional interconnection in this scenario suggests that fuel markets are less connected to energy stock markets, mainly due to the weakening of the cross-market spillover transmitted by natural gas to other actors, which reduced from more than 60% in the extreme quantiles to 5.6% in the intermediate quantile. Only crude oil maintains a high cross-market to other spillover (41.3%). These findings have two practical implications. First, promoting regulations aimed at reducing the participation of natural gas as an energy source may be an appropriate policy to accelerate the transition process because this fuel imposes lower dependence costs in comparison to oil. Second, as a result of the lower degree of exposure of the natural gas to the shocks transmission, investors can diversify risk by incorporating this fuel into their portfolios.

Table 3 presents the connectedness statistics between fuel and energy stock markets at the level of sectors and country-sectors. The results show certain similarities to those observed in the analysis at country-level, highlighting three essential aspects for investment and energy policy decisions. First, the quantiles of extreme returns present more intense and symmetrical connections, where both specific-market and cross-market spillovers have a relevant participation on total connectedness. At the sector-level, the system's total spillover reached a figure of 75.4% in high-returns scenario (95% quantile), which is decomposed into a specific-market spillover of 36.9% and a cross-market spillover of 38.5%. For its part, in low-returns scenario (5% quantile), the system spillover was 75.5%, where 37.0% and 38.5% correspond to specific-market and cross-market spillovers, respectively. This analysis suggests that the system's connectedness between fuel and energy stock markets at sector-level is almost equally explained by the interactions that develop both within and between these markets. However, when we analyze the energy stock markets through a sectoral portfolio within the same country (country-sector), the incidence of cross-market spillover weakens drastically. For the quantiles of 95% and 5% of the return distribution, spillovers registered global figures of 94.3% and 94.8%, respectively. In both cases, most of the system's connectedness was concentrated in specific-market spillover (about 80% in each quantile), while the contribution of cross-market spillover decreased to less than a fifth of all global interconnection (approximately since 38% at sector-level to 14% at country-sector-level). This finding confirms that oil and natural gas markets can transmit relevant shocks to the different sectors of the energy stock markets, and vice versa. However, the lower incidence of cross-market spillover on the system's connectedness at country-sector-level in comparison to the sector-level approach reveals greater spaces for portfolio diversification composed by energy sectors from different countries in both bullish and bearish scenarios. Naturally, this fact is because there are countries that are more or less vulnerable to fuel price shocks.

Second, we precisely identify the energy sectors most and least sensitive to the shocks transmission in extreme scenarios. On the one hand, the Oil and Gas Producers (OP) and Oil and Gas Services (OS) sectors are the actors that transmit the largest spillovers in both bullish and bearish scenarios, mainly in the United States, Canada, Spain and United Kingdom. In fact, they are the sectors with the greatest impact on specific-market spillover (to and from others), and therefore on the interactions within the energy stock markets.

Obviously, these country and sectors represent a great challenge for energy authorities, since due to their systemic relevance in global energy markets and their greater dependence on fuel markets, they make the energy transition process more difficult. On the other hand, the renewable energy (RE) and utilities (UT) sectors are identified as the least vulnerable actors of the system in the extreme quantiles. These sectors are net shocks receivers, transmit the lowest spillovers in these scenarios and are focus in the markets of China and Japan. Along with them, the lower connectedness of fuels, especially natural gas, configure a set of important investment alternatives to diversify portfolios in this industry.

Third, the most and least vulnerable sectors have a similar configuration to that described in extreme scenarios. However, we observe that the system's total connectedness for the 50% quantile was lower than that recorded at the extremes of the returns distribution, reaching a figure of 37.2%. From this connectedness measure, the specific-market spillover captures 22.8% and only 14.4% is attributed to cross-market spillover. In this way, a 38.62% ($14.4/37.2$) of the total spillover is supported by mutual interconnections, and evidently the fuel markets develop a channel of financial contagion on the energy stock markets that needs to be monitored with special emphasis. However, when we analyze the energy stock markets through a sectoral portfolio within the same country (country-sector), the weakening of cross-market spillover (6.3%) on total connectedness (65%) is even deeper than in the extreme quantiles, achieving an incidence of $6.3/65.5=10.7\%$. As observed in the analysis at country-level (Table 2), the average scenarios are characterized by a progressive decrease in the total spillovers of the energy system, and particularly by a substantial weakening of the incidence of fuel markets (cross-market spillover), aspects that essentially allow exploiting the advantages of sectoral (utilities and renewable energies) and international (China and Japan) diversification opportunities. Appendix A3 presents all connectedness statistics for the energy system at country-sector level.

Table 3. Spillover decomposition between energy stock and fuel markets: sector-level.

Sector	ID code	Total spillover index			Specific-market spillover (internal)			Cross-market spillover (external)		
		To other	From others	Net	To other	From others	Net	To other	From others	Net
<i>A. 95th quantile of return's distribution</i>										
Sector-level system		75.4	75.4	0.0	36.9	36.9	0.0	38.5	38.5	0.0
Utilities	UT	73.7	75.0	-1.3	46.2	48.9	-2.7	27.5	26.1	1.4
Oil and Gas Producers	OP	87.4	77.8	9.7	54.3	49.4	4.9	33.1	28.4	4.7
Oil and Gas Services	OS	86.0	77.6	8.4	53.2	49.2	4.0	32.9	28.4	4.4
Renewables energies	RE	68.0	74.6	-6.6	40.9	47.1	-6.2	27.1	27.5	-0.3
Natural Gas	NGAS	60.3	71.8	-11.5	12.4	14.6	-2.2	47.9	57.2	-9.3
Oil	OIL	77.1	75.8	1.3	14.6	12.4	2.2	62.5	63.4	-1.0
Country-sector spillover		94.3	94.3	0.0	79.9	79.9	0.0	14.4	14.4	0.0
Top-5 less-connected markets		89.2	94.1	-4.9	66.2	69.8	-3.7	23.0	24.3	-1.3
Fuel markets	NGAS	88.6	93.8	-5.2	3.8	4.2	-0.4	84.8	89.6	-4.8
Oil and Gas Services	CH.OS	89.0	94.4	-5.4	81.5	86.4	-4.9	7.5	8.0	-0.5
Oil and Gas Producers	CH.OP	89.2	94.2	-5.0	81.7	86.3	-4.6	7.5	7.9	-0.4
Utilities	JP.UT	89.4	94.2	-4.8	81.8	86.2	-4.4	7.6	8.1	-0.5
Utilities	CH.UT	89.7	94.0	-4.3	82.1	86.2	-4.1	7.6	7.7	-0.2
Top-5 more-connected markets		99.3	94.4	4.9	90.9	86.5	4.5	8.3	7.9	0.4
Oil and Gas Producers	US.OP	99.9	94.5	5.4	91.4	86.4	5.0	8.4	8.1	0.4
Oil and Gas Services	CA.OS	99.2	94.2	5.0	90.7	86.2	4.5	8.5	8.0	0.5
Oil and Gas Producers	SP.OP	99.2	94.5	4.7	91.0	86.8	4.3	8.1	7.7	0.4
Oil and Gas Producers	UK.OP	99.1	94.3	4.8	90.9	86.6	4.3	8.2	7.8	0.5
Oil and Gas Producers	CA.OP	99.0	94.5	4.5	90.7	86.5	4.2	8.3	8.0	0.4
<i>B. 50th quantile of return's distribution</i>										
	ID code	To other	From others	Net	To other	From others	Net	To other	From others	Net
Sector-level system		37.2	37.2	0.0	22.8	22.8	0.0	14.4	14.4	0.0
Utilities	UT	28.5	34.8	-6.3	24.0	30.1	-6.1	4.5	4.7	-0.2
Oil and Gas Producers	OP	74.9	59.8	15.1	53.3	43.9	9.3	21.6	15.9	5.7
Oil and Gas Services	OS	67.7	58.1	9.7	48.2	43.2	5.0	19.5	14.8	4.7
Renewables energies	RE	11.3	20.3	-9.0	9.1	17.4	-8.2	2.1	2.9	-0.8
Natural Gas	NGAS	3.5	5.3	-1.8	0.9	1.4	-0.5	2.6	4.0	-1.4
Oil	OIL	37.1	44.7	-7.6	1.4	0.9	0.5	35.7	43.8	-8.1
Country-sector spillover		65.0	65.0	0.0	58.7	58.7	0.0	6.3	6.3	0.0
Top-5 less-connected markets		22.5	42.9	-20.4	19.6	37.5	-17.9	2.9	5.4	-2.6
Fuel markets	NGAS	10.1	21.4	-11.4	0.5	1.1	-0.6	9.6	20.3	-10.8
Utilities	JP.UT	15.7	44.8	-29.2	14.6	43.3	-28.7	1.1	1.6	-0.5
Renewables energies	JP.RE	18.5	49.4	-30.9	17.3	47.8	-30.5	1.2	1.7	-0.5
Renewables energies	CA.RE	29.3	46.7	-17.4	27.9	45.1	-17.1	1.4	1.6	-0.3
Oil and Gas Services	CH.OS	38.9	52.0	-13.1	37.7	50.1	-12.4	1.2	1.9	-0.7
Top-5 more-connected markets		105.3	79.6	25.7	97.1	74.3	22.7	8.3	5.3	3.0
Oil and Gas Producers	US.OP	113.8	80.4	33.4	103.1	73.7	29.4	10.7	6.7	4.0
Oil and Gas Services	US.OS	107.9	79.8	28.1	97.7	73.3	24.4	10.1	6.5	3.6
Oil and Gas Producers	CA.OP	107.5	79.7	27.9	97.1	73.1	24.0	10.4	6.6	3.9
Oil and Gas Producers	IT.OP	104.2	80.0	24.2	99.0	76.7	22.3	5.2	3.3	1.9
Oil and Gas Producers	SP.OP	93.4	78.3	15.1	88.4	75.0	13.4	5.0	3.3	1.7
<i>C. 5th quantile of return's distribution</i>										
	ID code	To other	From others	Net	To other	From others	Net	To other	From others	Net
Sector-level system		75.5	75.5	0.0	37.0	37.0	0.0	38.5	38.5	0.0
Utilities	UT	75.6	75.8	-0.2	47.0	49.1	-2.1	28.6	26.7	1.9
Oil and Gas Producers	OP	87.4	78.0	9.5	54.3	49.6	4.7	33.2	28.4	4.8
Oil and Gas Services	OS	85.6	77.8	7.8	53.0	49.4	3.6	32.6	28.4	4.2
Renewables energies	RE	67.5	73.9	-6.4	41.1	47.2	-6.2	26.4	26.6	-0.2
Natural Gas	NGAS	58.5	71.3	-12.8	12.0	14.8	-2.8	46.5	56.5	-10.0
Oil	OIL	78.5	76.4	2.0	14.8	12.0	2.8	63.7	64.4	-0.7
Country-sector spillover		94.8	94.8	0.0	80.5	80.5	0.0	14.3	14.3	0.0
Top-5 less-connected markets		86.6	94.8	-8.2	64.8	70.6	-5.8	21.8	24.2	-2.4
Fuel markets	NGAS	83.2	94.5	-11.3	3.5	4.2	-0.7	79.7	90.3	-10.6
Renewables energies	JP.RE	85.1	95.2	-10.1	78.0	87.4	-9.4	7.1	7.7	-0.7
Utilities	JP.UT	86.7	95.0	-8.3	79.5	87.4	-7.9	7.2	7.6	-0.4
Oil and Gas Services	CH.OS	88.6	94.8	-6.2	81.1	87.1	-6.0	7.4	7.7	-0.2
Renewables energies	CA.RE	89.3	94.6	-5.3	81.8	86.9	-5.1	7.5	7.7	-0.2
Top-5 more-connected markets		100.6	94.7	5.8	74.7	70.4	4.4	25.8	24.4	1.4
Oil and Gas Producers	US.OP	101.8	94.8	7.0	93.2	87.1	6.1	8.6	7.8	0.8
Oil and Gas Producers	CA.OP	101.4	94.8	6.5	92.8	87.1	5.8	8.6	7.8	0.8
Oil and Gas Services	US.OS	100.5	94.8	5.7	92.1	87.1	5.0	8.4	7.7	0.7
Utilities	CA.UT	99.7	94.7	5.0	91.4	87.1	4.3	8.2	7.6	0.6
Fuel markets	OIL	99.5	94.6	4.9	4.2	3.5	0.7	95.3	91.1	4.3

Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. We use a classification of $q = 2$ groups or markets, defined as fuel (natural gas and oil) and energy stock markets. Source: Authors.

Tables 4 and 5 show the top-20 energy firms (or fuels) most and least connected within the global network. To do this, companies and fuels were classified according to the highest and lowest spillovers transmitted to others actors within the system, respectively. In comparison to the empirical contributions of the most recent studies (Pham et al., 2023; Naeem et al., 2024), this disaggregated analysis at firm-level provides two new findings about the connectedness between the fuel and energy stock markets. First, the spillovers between fuel and the 118 energy firms are more homogeneous over time and across all quantiles of the returns distribution. The total connectedness indices were 99.1%, 98.9% and 99.1% for the 95%, 50% and 5% quantiles, respectively. Second, the contribution of specific-market spillover dominates on system's total connectedness, leaving little participation to cross-market spillover. The specific-market spillovers were 95.75%, 95.74% and 95.88% for the quantiles of 95%, 50% and 5%, while the cross-markets spillovers only contributed 3.39%, 3.16% and 3.26% for the same quantiles. These results demonstrate that almost all system connectedness come from the interactions between the energy firms of stock markets; and that the bidirectional link between fuels and these companies has a limited participation in the total interconnection. This finding not only differs from the analyzes at the country, sector and country-sector levels described in the previous sections, but also from studies that describe more intense spillovers only at the extreme quantiles of the returns distribution (Pham et al., 2023) or a greater contribution by fuels to the total spillover (Feng et al., 2023). Naturally, the lower incidence of fuels on system's connectedness not only opens up opportunities for diversification in the energy industry, but also warns about the need to consider disaggregated information at firm-level to design energy regulations that more accurately quantify the costs and pathways to transition towards renewable sources.

Table 4 presents the top-20 most connected actors in the global network considering the highest spillovers transmitted to others. These firms and/or fuels are net shocks transmitters within the energy system. In fact, the average spillovers (to others) of these firms and/or fuels most vulnerable to the shocks transmission were 104.16%, 112.13% and 105.50% for the quantiles of 95%, 50% and 5%, respectively, records that are above the system's average spillover in each scenario. The specific-market spillover continues to be the most relevant connectedness measure in the energy system, leaving little participation to cross-market spillover across quantiles. As is evident, a lot of the total connectedness come from within each market rather than between them, where the US energy firms are the main actors in the shocks transmission. Furthermore, across the 95%, 50% and 5% quantiles of the return distribution, we precisely identified seven US energy companies that are characterized by transmitting high spillovers within the global network. Firms in the utilities sectors (DTE Energy Corp., Consolidated Edison Inc., WEC Energy Group Inc., and Xcel Energy Inc.), Oil and Gas Producers (Marathon Oil Corp., Murphy Oil Corp.) and Oil and Gas Services (Halliburton Corp.) are characterized by being highly vulnerable to shocks to the energy system. Duke Energy Corp. and Southern Corp., are two US utility firms, which transmit important shocks only in bullish and bearish scenarios. In addition, fuels also are one of actors more connected and vulnerable to the shocks transmission in these extreme scenarios. These findings suggest two essential aspects for both investment decisions and energy policy formulation. On the one hand, it is evident that the systemic relevance of US firms within the global network limits the spaces for diversification and

exposes energy portfolios to greater sources of financial contagion, and in the same way, the high dependence between these firms impose greater restrictions on energy regulations aimed at promoting the energy transition and reduced use of fossil fuels. Appendices A4, A5 and A6 present the connectedness statistics for fuels and all energy companies.

Table 5 presents the top-20 least vulnerable firms and/or fuels in the energy network considering the lowest spillovers transmitted to others. These actors less connected to the energy system transmit spillovers of 94.10%, 85.40% and 93.00% in the quantiles of 95%, 50% and 5% of the returns distribution, respectively. These connectedness figures are below the average spillover of each quantiles, and characterize these actors as net shocks receivers. In all these cases, the contribution of specific-market spillover is the most relevant over the system's spillover. In fact, the internal spillovers (to other) were 92.52%, 79.83% and 86.89% in the quantiles of 95%, 50% and 5% of the returns distribution, while the cross-market or external spillover (to other) only reached figures of 1.58%, 5.57% and 6.11% for those quantiles. Undoubtedly, the weakening of mutual connectedness between these markets opens important spaces for risk diversification within the least vulnerable actors in each scenario. In a bullish scenario, several Canadian utility companies (ATCO Ltd., Northland Power Inc., AltaGas Ltd., Emera Inc., Canadian Utilities Limited) and oil producers (Keyera Corp., Enbridge Inc.), along with other energy companies from Spain (Repsol SA, Endesa SA, Naturgy Energy Group SA, Red Electrica Corp SA), Italy (Enel SpA, Saipem SpA, Snam SpA) and the United Kingdom (National Grid PLC., SSE PLC) make up an important set of opportunities to diversify the risk in energy portfolios. In average-returns (50% quantile) and low-returns (5% quantile) scenarios, Chinese energy firms stand out within the set of less vulnerable actors. This is the case of China Petroleum & Chemical Corporation, Offshore Oil Engineering Corp., Guangdong Meiyuan Jixiang Hydropower Corp., Guangxi Guiguan Electric Power Corp., Inner Mongolia Mengdian Huaneng Thermal Power Corporation, Guanghui Energy Corp., and Huadian Energy Corp. Appendices A4, A5 and A6 present the connectedness statistics for fuels and all energy companies.

Despite the weaker cross-market linkage between the fuel and energy stock markets in each quantile, it is important to highlight three relevant aspects for the energy policy debate. First, in terms of the total connectedness in energy markets, fuels only have a greater impact on external spillovers (cross-market) and of these, oil transmits the greatest spillovers. Second, oil is one of the actors most connected to the global network in bullish and bearish scenarios, and because of its position in the system, this fuel transmits intense shocks. These aspects are crucial for the design of energy regulations since the high oil financialization imposes higher costs on transition policies towards renewable sources in extreme scenarios. Third, natural gas has an important role for risk spread in bullish scenarios, but it is a risk diversification source in average and bearish scenarios. This fact suggests that natural gas not only transmits asymmetric shocks on energy markets (Uribe et al., 2022; Pham et al., 2023; Chuliá et al., 2024), but that its lower links in some scenarios would contribute to accelerating policies aimed at reducing its consumption and counteract the effects of climate change and the use of fossil fuels.

Table 4. Spillovers between energy stock and fuel markets: Top-20 more-connected.

Country	Firms ID code	Total spillover index			Specific-market spillover (internal)			Cross-market spillover (external)		
		To other	From others	Net	To other	From others	Net	To other	From others	Net
<i>A. 95th quantile of return's distribution</i>										
Fuels	NGAS	108.19	99.07	9.11	0.90	0.89	0.02	107.28	98.19	9.10
United States	US13	107.17	99.08	8.09	105.38	97.30	8.09	1.79	1.79	0.01
United States	US25	106.75	99.08	7.67	104.95	97.30	7.65	1.80	1.78	0.01
United States	US33	105.94	99.09	6.85	104.13	97.28	6.85	1.81	1.80	0.00
Canada	CA26	105.53	99.08	6.45	103.76	97.28	6.48	1.77	1.80	-0.03
United States	US40	104.67	99.09	5.58	102.93	97.30	5.63	1.74	1.79	-0.05
United States	US12	104.58	99.11	5.47	102.82	97.33	5.49	1.77	1.78	-0.01
Fuels	OIL	104.55	99.11	5.45	0.89	0.90	-0.02	103.67	98.20	5.47
United States	US42	103.89	99.08	4.81	102.15	97.30	4.85	1.74	1.78	-0.03
United States	US16	103.85	99.11	4.75	102.10	97.30	4.80	1.75	1.80	-0.05
United States	US11	103.58	99.10	4.48	101.85	97.30	4.54	1.73	1.80	-0.07
United States	US21	103.37	99.10	4.27	101.63	97.30	4.33	1.74	1.80	-0.06
United States	US41	102.99	99.11	3.88	101.28	97.32	3.96	1.72	1.79	-0.07
United States	US38	102.89	99.12	3.77	101.17	97.34	3.83	1.72	1.78	-0.07
United States	US04	102.83	99.09	3.74	101.10	97.30	3.80	1.73	1.79	-0.06
United States	US36	102.80	99.12	3.69	101.08	97.32	3.75	1.73	1.79	-0.07
United States	US14	102.52	99.10	3.41	100.80	97.33	3.48	1.72	1.78	-0.06
United States	US26	102.42	99.12	3.29	100.70	97.32	3.38	1.72	1.80	-0.09
Canada	CA01	102.40	99.12	3.29	100.68	97.32	3.36	1.72	1.79	-0.07
United States	US22	102.29	99.14	3.15	100.57	97.33	3.24	1.72	1.80	-0.08
Top-20 more-connected average		104.16	99.10	5.06	92.04	87.67	4.37	12.12	11.43	0.69
Full sample average		99.14	99.14	0.00	95.75	95.75	0.00	3.39	3.39	0.00
<i>B. 50th quantile of return's distribution</i>										
United States	US13	119.02	98.77	20.25	117.02	97.21	19.81	2.00	1.56	0.44
United States	US08	118.94	98.77	20.17	116.93	97.19	19.74	2.01	1.57	0.44
United States	US25	115.36	98.81	16.54	113.41	97.24	16.17	1.95	1.58	0.37
United States	US42	115.32	98.81	16.51	113.40	97.27	16.13	1.92	1.54	0.38
Italy	IT01	114.07	98.83	15.24	112.14	97.27	14.87	1.93	1.56	0.38
United States	US40	113.12	98.82	14.30	111.23	97.28	13.96	1.88	1.54	0.34
United States	US05	112.81	98.83	13.98	110.94	97.29	13.65	1.87	1.54	0.33
United States	US01	111.88	98.82	13.06	110.01	97.28	12.73	1.86	1.54	0.33
United States	US09	111.61	98.84	12.77	109.72	97.28	12.44	1.90	1.56	0.33
United States	US02	111.40	98.84	12.56	109.54	97.30	12.24	1.85	1.54	0.32
United States	US23	111.37	98.86	12.51	109.49	97.28	12.21	1.88	1.58	0.31
United States	US22	110.96	98.84	12.13	109.10	97.28	11.82	1.87	1.56	0.31
Canada	CA05	110.72	98.84	11.88	108.85	97.27	11.58	1.87	1.57	0.30
United States	US26	110.68	98.82	11.86	108.82	97.25	11.58	1.86	1.57	0.28
United States	US16	110.01	98.87	11.14	108.14	97.30	10.84	1.87	1.57	0.30
Canada	CA16	109.68	98.84	10.84	107.82	97.28	10.55	1.86	1.57	0.30
United States	US04	108.96	98.87	10.08	107.12	97.30	9.82	1.83	1.57	0.26
United States	US31	108.94	98.86	10.08	107.11	97.34	9.78	1.83	1.52	0.30
United States	US11	108.86	98.87	9.99	107.07	97.34	9.73	1.79	1.53	0.26
United States	US14	108.80	98.85	9.96	106.98	97.30	9.68	1.83	1.55	0.28
Top-20 more-connected average		112.13	98.83	13.29	110.24	97.28	12.97	1.88	1.55	0.33
Full sample average		98.91	98.91	0.00	95.74	95.74	0.00	3.16	3.16	0.00
<i>C. 5th quantile of return's distribution</i>										
United States	US01	111.60	99.04	12.57	109.73	97.41	12.32	1.87	1.63	0.24
United States	US36	110.28	99.04	11.25	108.44	97.36	11.08	1.84	1.67	0.16
United States	US12	108.21	99.05	9.15	106.39	97.40	8.98	1.82	1.65	0.17
United States	US14	106.47	99.08	7.38	104.69	97.43	7.26	1.77	1.65	0.12
United States	US30	106.44	99.08	7.36	104.66	97.43	7.24	1.77	1.65	0.13
United States	US42	106.22	99.08	7.14	104.47	97.44	7.03	1.76	1.65	0.11
United States	US40	106.09	99.08	7.01	104.32	97.43	6.90	1.77	1.65	0.12
United States	US25	105.88	99.08	6.80	104.11	97.41	6.70	1.77	1.67	0.10
United States	US05	104.96	99.08	5.87	103.21	97.44	5.77	1.75	1.64	0.11
Spain	SP01	104.66	99.10	5.56	102.91	97.45	5.46	1.76	1.65	0.11
United States	US26	104.61	99.08	5.53	102.87	97.42	5.45	1.74	1.66	0.08
United States	US11	104.34	99.11	5.23	102.59	97.47	5.12	1.76	1.64	0.12
United States	US02	104.34	99.09	5.25	102.59	97.46	5.13	1.75	1.64	0.11
United States	US31	104.15	99.09	5.06	102.39	97.46	4.93	1.77	1.63	0.13
United States	US28	104.06	99.08	4.98	102.34	97.45	4.90	1.72	1.64	0.08
United States	US35	103.93	99.09	4.84	102.18	97.44	4.75	1.75	1.66	0.09
United States	US20	103.73	99.10	4.63	102.00	97.45	4.55	1.73	1.65	0.08
United States	US22	103.65	99.09	4.55	101.89	97.44	4.45	1.76	1.65	0.11
United States	US18	103.33	99.10	4.23	101.59	97.44	4.15	1.74	1.66	0.08
Fuels	OIL	102.99	99.11	3.88	0.87	0.79	0.09	102.11	98.32	3.79
Top-20 more-connected average		105.50	99.08	6.41	98.71	92.60	6.11	6.78	6.48	0.30
Full sample average		99.14	99.14	0.00	95.88	95.88	0.00	3.26	3.26	0.00

Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPSS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. We use a classification of $q = 2$ groups or markets, defined as fuel (natural gas and oil) and energy stock markets. Source: Authors.

Table 5. Spillovers between energy stock and fuel markets: Top-20 less-connected.

Country	Firms ID code	Total spillover index			Specific-market spillover (internal)			Cross-market spillover (external)		
		To other	From others	Net	To other	From others	Net	To other	From others	Net
<i>A. 95th quantile of return's distribution</i>										
Spain	SP03	86.92	99.27	-12.35	85.47	97.48	-12.01	1.45	1.78	-0.34
Canada	CA17	93.12	99.20	-6.07	91.56	97.43	-5.87	1.56	1.77	-0.21
China	CH15	93.41	99.19	-5.77	91.84	97.41	-5.57	1.57	1.78	-0.21
United Kingdom	UK02	93.44	99.20	-5.76	91.90	97.39	-5.50	1.54	1.81	-0.27
Spain	SP05	93.82	99.18	-5.36	92.25	97.39	-5.14	1.57	1.79	-0.23
Italy	IT04	93.83	99.19	-5.36	92.27	97.42	-5.15	1.56	1.77	-0.21
China	CH12	94.09	99.17	-5.09	92.51	97.40	-4.89	1.58	1.77	-0.19
Italy	IT03	94.22	99.19	-4.98	92.63	97.38	-4.75	1.58	1.81	-0.22
Norway	NW02	94.24	99.19	-4.95	92.66	97.38	-4.72	1.59	1.81	-0.23
France	FR01	94.44	99.18	-4.74	92.85	97.42	-4.57	1.59	1.76	-0.17
Italy	IT02	94.73	99.17	-4.44	93.14	97.37	-4.23	1.59	1.80	-0.21
Canada	CA07	94.74	99.19	-4.45	93.14	97.42	-4.28	1.60	1.77	-0.17
Canada	CA12	94.79	99.18	-4.39	93.17	97.38	-4.21	1.62	1.80	-0.18
United Kingdom	UK03	94.85	99.19	-4.34	93.28	97.41	-4.13	1.57	1.78	-0.22
Spain	SP02	94.86	99.19	-4.34	93.25	97.42	-4.17	1.60	1.77	-0.17
Canada	CA11	94.97	99.18	-4.21	93.35	97.40	-4.05	1.62	1.78	-0.16
Canada	CA08	95.18	99.18	-4.00	93.57	97.40	-3.84	1.61	1.78	-0.16
Canada	CA10	95.24	99.18	-3.94	93.63	97.42	-3.80	1.62	1.76	-0.14
Canada	CA19	95.46	99.18	-3.72	93.85	97.39	-3.54	1.61	1.78	-0.18
Spain	SP04	95.72	99.16	-3.44	94.13	97.37	-3.24	1.59	1.79	-0.20
Top-20 less-connected average		94.10	99.19	-5.09	92.52	97.40	-4.88	1.58	1.78	-0.20
Full sample average		99.14	99.14	0.00	95.75	95.75	0.00	3.39	3.39	0.00
<i>B. 50th quantile of return's distribution</i>										
China	CH12	82.34	99.06	-16.72	80.94	97.51	-16.57	1.40	1.55	-0.15
United Kingdom	UK04	83.27	99.04	-15.77	81.87	97.49	-15.62	1.40	1.55	-0.15
Japan	JP01	83.45	99.04	-15.59	82.03	97.47	-15.43	1.41	1.57	-0.16
China	CH08	83.50	99.03	-15.53	82.09	97.47	-15.37	1.41	1.56	-0.15
Canada	CA01	83.59	98.93	-15.34	82.17	97.35	-15.18	1.42	1.58	-0.16
China	CH16	84.03	98.99	-14.96	82.61	97.42	-14.81	1.41	1.57	-0.15
China	CH13	84.27	99.03	-14.76	82.86	97.48	-14.62	1.42	1.56	-0.14
China	CH03	84.36	99.02	-14.66	82.95	97.47	-14.52	1.41	1.55	-0.14
China	CH06	84.71	99.04	-14.33	83.29	97.48	-14.20	1.42	1.56	-0.13
Fuels	NGAS	84.83	98.82	-13.99	0.71	0.84	-0.13	84.12	97.98	-13.86
China	CH01	85.91	98.98	-13.07	84.44	97.42	-12.98	1.47	1.56	-0.09
China	CH15	86.02	98.99	-12.96	84.57	97.45	-12.88	1.46	1.54	-0.09
China	CH11	86.16	98.94	-12.78	84.71	97.39	-12.68	1.45	1.55	-0.11
Canada	CA04	86.42	99.03	-12.62	84.94	97.45	-12.51	1.47	1.58	-0.11
China	CH05	86.65	98.95	-12.30	85.20	97.41	-12.21	1.46	1.55	-0.09
China	CH17	86.74	99.02	-12.28	85.29	97.45	-12.16	1.45	1.56	-0.12
China	CH09	87.62	98.97	-11.35	86.15	97.41	-11.25	1.47	1.56	-0.10
China	CH07	87.66	98.93	-11.27	86.21	97.38	-11.18	1.45	1.55	-0.10
China	CH04	88.19	99.00	-10.81	86.71	97.46	-10.75	1.48	1.54	-0.06
China	CH14	88.29	98.93	-10.63	86.80	97.36	-10.56	1.49	1.56	-0.07
Top-20 less-connected average		85.40	98.99	-13.59	79.83	92.61	-12.78	5.57	6.38	-0.81
Full sample average		98.91	98.91	0.00	95.74	95.74	0.00	3.16	3.16	0.00
<i>C. 5th quantile of return's distribution</i>										
China	CH06	90.04	99.23	-9.19	88.52	97.58	-9.05	1.52	1.65	-0.14
Canada	CA01	90.53	99.23	-8.70	89.03	97.58	-8.55	1.50	1.66	-0.15
China	CH01	91.61	99.21	-7.60	90.07	97.55	-7.48	1.54	1.66	-0.12
Canada	CA06	91.93	99.21	-7.28	90.37	97.59	-7.22	1.56	1.62	-0.06
Japan	JP06	92.06	99.22	-7.16	90.51	97.57	-7.06	1.55	1.65	-0.10
United Kingdom	UK04	92.11	99.20	-7.09	90.56	97.56	-7.00	1.55	1.64	-0.09
Japan	JP01	92.15	99.21	-7.06	90.61	97.55	-6.95	1.54	1.65	-0.11
Japan	JP04	92.83	99.20	-6.37	91.27	97.57	-6.30	1.56	1.63	-0.07
China	CH07	92.85	99.20	-6.35	91.30	97.56	-6.26	1.55	1.64	-0.08
Canada	CA12	93.13	99.21	-6.08	91.59	97.56	-5.98	1.54	1.65	-0.11
Fuels	NGAS	93.22	99.21	-5.99	0.79	0.87	-0.09	92.44	98.34	-5.90
Canada	CA10	93.45	99.20	-5.75	91.84	97.55	-5.71	1.61	1.65	-0.04
China	CH13	93.47	99.20	-5.73	91.89	97.56	-5.67	1.58	1.64	-0.06
Spain	SP04	93.81	99.20	-5.39	92.23	97.52	-5.29	1.58	1.68	-0.11
China	CH08	93.81	99.18	-5.37	92.24	97.54	-5.30	1.57	1.64	-0.07
China	CH11	94.13	99.19	-5.06	92.52	97.53	-5.01	1.61	1.66	-0.05
China	CH10	94.22	99.19	-4.96	92.64	97.53	-4.89	1.59	1.66	-0.07
Canada	CA19	94.81	99.18	-4.37	93.22	97.54	-4.32	1.59	1.64	-0.06
China	CH14	94.84	99.19	-4.35	93.25	97.54	-4.29	1.59	1.65	-0.05
Canada	CA14	94.95	99.19	-4.24	93.34	97.56	-4.22	1.61	1.63	-0.02
Top-20 less-connected average		93.00	99.20	-6.21	86.89	92.72	-5.83	6.11	6.48	-0.37
Full sample average		99.14	99.14	0.00	95.88	95.88	0.00	3.26	3.26	0.00

Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. We use a classification of $q = 2$ groups or markets, defined as fuel (natural gas and oil) and energy stock markets. Source: Authors.

6. Conclusions and discussion

Previous literature on connectedness between the fuel and stock markets is extensive, and a lot of it has confirmed the strong interconnection between them. However, this research contributes to the existing literature by covering two important knowledge gaps. First, various investigations have studied the links between fuel and stock markets using aggregate indices or a limited sample of energy companies under a mean-conditional connectedness approach. In this context, it is evident that their results have been partial since, on the one hand, they have not allowed to establish the systemic importance of certain firms or markets within the energy network, and on the other hand, they have persistently ignored the interconnections' structure between these actors in extreme scenarios or different from those considered normal. Second, all of them have focused on total connectedness to infer the link between these markets, overlooking the real incidence internal or external spillovers on the total connectedness of the system. Naturally, this distinction is crucial for investment strategies and energy policies.

Our research provides a set of four original results. First, our results revealed that the oil, natural gas and energy stock markets are closely interconnected. The total spillovers are dynamics and vary across the different quantiles of the return distribution. At country-level, the total connectedness indices were 86.9%, 50.8% and 87.4% for the 95%, 50% and 5% quantiles, respectively. Of these figures, specific-market spillovers, which quantify the internal linkages within each market, were 62.1%, 42.0% and 62.5%, while cross-market spillovers, associated to cross-interactions between them, reached figures of 24.8%, 8.8% and 24.9% for the same quantiles. At sector-level, the total connectedness registered spillovers of 75.4%, 37.2% and 75.5% for the quantiles of 95%, 50% and 5%, figures that were broken down into internal spillovers of 36.9%, 22.8% and 37.0%, and external spillovers 38.5%, 14.4% and 38.5%, for the respective quantiles of the return distribution. Finally, the total connectedness indices at firm-level were 99.1%, 98.9% and 99.1%, which include internal spillovers of 95.7%, 95.7% and 95.8%, and external spillovers of 3.4%, 3.2% and 3.3% for the same quantiles. Important implications emerge from these findings: *i*) in line with previous studies, both at the country and sector level, the connectedness between the fuel and energy stock markets is asymmetric along the quantiles of the returns distribution, being more intense and symmetrical at the extremes quantiles and lower in the intermediate ones; *ii*) at firm-level, the spillovers are more intense and symmetrical across the quantiles than what is observed at the level of countries or sectors. This suggests that the firms-level connectedness are more homogeneous and provide a more detailed description for investment or energy policy decision-making; *iii*) the incidence of specific-market spillover is crucial on the system's total interconnection. However, cross-market was also relevant at both the country and sector levels, which reveals the existence of a bidirectional contagion channel from the fuels to the energy stock market; *iv*) at firm-level, cross-market spillover fades drastically. Therefore, studies based on an aggregated approach can overestimate the true shocks transmitted by fuels on energy stock markets, biasing the investment decisions and energy policies.

Second, the most connected and vulnerable actors to the shocks transmission are precisely identified. From their central position in the network, these actors transmit the most intense shocks, making them the main net transmitters of the system. At country-

level, we identify the energy stock markets of North America (United States, Canada) and Europe (United Kingdom, Italy, Spain, France, Germany, Norway) as the main shocks transmitters in both bullish and bearish scenarios. In close to the average quantiles, these markets continue to be the main protagonists in the risks contagion, although the spillovers are less intense. Oil and Gas Producers (OP) and Oil and Gas Services (OS) sectors are the most important transmitters of spillovers, both in bullish and bearish scenarios, mainly from the United States, Canada, Spain and the United Kingdom. At firm-level, US energy firms are relevant in the shocks transmission across different quantiles. Utilities firms (DTE Energy Corp., Consolidated Edison Inc., WEC Energy Group Inc., and Xcel Energy Inc.), Oil and Gas Producers (Marathon Oil Corp., Murphy Oil Corp.) and Oil and Gas Services (Halliburton Corp.) are highly vulnerable to system shocks. Naturally, all these actors restrict the diversification opportunities and energy transition policies.

Third, the least connected actors in the energy system are also identified. These actors are located in the peripheral areas of the global network, a position from which they are less exposed to the shocks transmission from the rest of the energy system. At country-level, China and Japan stand out as the energy stock markets least connected to the global network across the different quantiles of the returns distribution. Renewable energy (RE) and utilities (UT) sectors are the least vulnerable energy sectors, mainly in the extreme quantiles. These sectors are also net shocks receivers, transmit the lowest spillovers in these scenarios, and are mainly represented by the markets of China and Japan. In the average scenario, these markets and sectors offer important diversification advantages not only because they are less exposed to system's shocks, but also because these scenarios have lower spillovers than in the extremes. The diversification opportunities description at firm-level is more heterogeneous between quantiles and countries. On the one hand, various Canadian utility companies (ATCO Ltd., Northland Power Inc., AltaGas Ltd., Emera Inc., Canadian Utilities Limited) and fuel producers (Keyera Corp., Enbridge Inc.), along with other energy companies from Spain (Repsol SA, Endesa SA, Naturgy Energy Group SA, Red Electrica Corp SA), Italy (Enel SpA, Saipem SpA, Snam SpA) and the United Kingdom (National Grid PLC., SSE PLC) make up important alternatives for risk diversification in bullish scenarios. On the other hand, in the average and bearish scenarios, Chinese firms such as China Petroleum & Chemical Corp., Offshore Oil Engineering Corp., Guangdong Meiyang Jixiang Hydropower Corp., Guangxi Guiguan Electric Power Corp., Inner Mongolia Mengdian Huaneng Thermal Power Corp., Guanghui Energy Corp., and Huadian Energy Corp., are less vulnerable. These markets, sectors and firms not only provide important diversification alternatives, but also establish a precise route for energy regulations focused on accelerating the energy transition and reducing the fossil fuels' role.

Fourth, the roles of natural gas and oil within the energy network are also established. At country or sector level, oil and natural gas are markets with a low interconnection within the global network across the different quantiles of the returns distribution. Regarding natural gas, our results showed that it offers important advantages to diversify risk in bullish, average and bearish scenarios. However, at firm-level, natural gas offers such advantages only in average and bearish scenarios, since in high-returns quantiles this market has the capacity to transmit stronger shocks. Regarding oil, our findings confirmed that it propagates shocks more intense than natural gas prices. Its spillovers are particularly greater in extreme scenarios under a firm-level approach.

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Appendix

Appendix A1. Sample of energy firms.

Country	ID	Firms	Industry
Canada	CA01	Ballard Power Systems Inc.	Renewable Energy
	CA02	Pembina Pipeline Corporation	Oil & Gas Producers
	CA03	Crescent Point Energy Corp.	Oil & Gas Producers
	CA04	Boralex Inc.	Utilities
	CA05	Suncor Energy, Inc.	Oil & Gas Producers
	CA06	Parkland Corporation	Oil & Gas Producers
	CA07	ATCO Ltd.	Utilities
	CA08	Northland Power Inc.	Utilities
	CA09	Algonquin Power & Utilities Corp.	Utilities
	CA10	AltaGas Ltd.	Utilities
	CA11	Emera Inc.	Utilities
	CA12	Keyera Corp.	Oil & Gas Producers
	CA13	TC Energy Corporation	Oil & Gas Producers
	CA14	Imperial Oil Ltd.	Oil & Gas Producers
	CA15	Brookfield Renewable Partners L.P.	Utilities
	CA16	Canadian Natural Resources Ltd.	Oil & Gas Producers
	CA17	Canadian Utilities Limited	Utilities
	CA18	Fortis, Inc.	Utilities
	CA19	Enbridge Inc.	Oil & Gas Producers
	CA20	TransAlta Corporation	Utilities
	CA21	Vermilion Energy, Inc.	Oil & Gas Producers
	CA22	ARC Resources Ltd.	Oil & Gas Producers
	CA23	Enerplus Corp.	Oil & Gas Producers
	CA24	Ensign Energy Services Inc	Oil & Gas Services
	CA25	Trican Well Service Ltd.	Oil & Gas Services
	CA26	Precision Drilling Corporation	Oil & Gas Services
	CA27	Paramount Resources Ltd.	Oil & Gas Producers
United States	US01	Ameren Corp	Utilities
	US02	American Electric Power Co Inc	Utilities
	US03	AES Corp	Utilities
	US04	APA Corp	Oil & Gas Producers
	US05	CMS Energy Corp	Utilities
	US06	CenterPoint Energy Inc	Utilities
	US07	CNX Resources Corp	Oil & Gas Producers
	US08	ConocoPhillips	Oil & Gas Producers
	US09	Chevron Corp	Oil & Gas Producers
	US10	Dominion Energy Inc	Utilities
	US11	DTE Energy Co	Utilities
	US12	Duke Energy Corp	Utilities
	US13	Devon Energy Corp	Oil & Gas Producers
	US14	Consolidated Edison Inc	Utilities
	US15	Edison International	Utilities
	US16	EOG Resources Inc	Oil & Gas Producers
	US17	EQT Corp	Oil & Gas Producers
	US18	Entergy Corp	Utilities
	US19	Exelon Corp	Utilities
	US20	FirstEnergy Corp	Utilities
	US21	TechnipFMC PLC	Oil & Gas Services
	US22	Halliburton Co	Oil & Gas Services
	US23	Hess Corp	Oil & Gas Producers
	US24	Helmerich & Payne Inc	Oil & Gas Services
	US25	Marathon Oil Corp	Oil & Gas Producers
	US26	Murphy Oil Corp	Oil & Gas Producers
	US27	NiSource Inc	Utilities
	US28	NOV Inc	Oil & Gas Services
	US29	NRG Energy Inc	Utilities
	US30	Public Service Enterprise Group Inc	Utilities
	US31	Pinnacle West Capital Corp	Utilities
	US32	PPL Corp	Utilities
	US33	Pioneer Natural Resources Co	Oil & Gas Producers
	US34	Range Resources Corp	Oil & Gas Producers

	US35	Schlumberger NV	Oil & Gas Services
	US36	Southern Co	Utilities
	US37	Sempra Energy	Utilities
	US38	Southwestern Energy Co	Oil & Gas Producers
	US39	Valero Energy Corp	Oil & Gas Producers
	US40	WEC Energy Group Inc	Utilities
	US41	Williams Cos Inc	Oil & Gas Producers
	US42	Xcel Energy Inc	Utilities
	US43	Exxon Mobil Corp	Oil & Gas Producers
China	CH01	China Petroleum & Chemical Corporation	Oil & Gas Producers
	CH02	GD Power Development Co. Ltd.	Utilities
	CH03	Huaneng Power International, Inc.	Utilities
	CH04	Shenergy Company Limited	Utilities
	CH05	Shenzhen Energy Group Co., Ltd.	Utilities
	CH06	Offshore Oil Engineering Co., Ltd.	Oil & Gas Services
	CH07	Guangdong Meiyuan Jixiang Hydropower Co., Ltd.	Utilities
	CH08	Guangxi Guiguan Electric Power Co.,Ltd.	Utilities
	CH09	Guangdong Electric Power Development Co.,Ltd.	Utilities
	CH10	Shanghai Dazhong Public Utilities (Group) Co., Ltd.	Utilities
	CH11	Inner Mongolia Mengdian Huaneng Thermal Power Corporation Limited	Utilities
	CH12	Changchun Gas Co., Ltd.	Utilities
	CH13	Guanghui Energy Co., Ltd.	Oil & Gas Producers
	CH14	Huadian Energy Co., Ltd.	Utilities
	CH15	Sichuan Chuantou Energy Co., Ltd.	Utilities
	CH16	Shenzhen Guangju Energy Co., Ltd.	Oil & Gas Producers
	CH17	An Hui Wenergy Co., Ltd.	Utilities
Japan	JP01	GS Yuasa Corporation	Renewable Energy
	JP02	Tokyo Gas Co., Ltd.	Utilities
	JP03	Osaka Gas Co., Ltd.	Utilities
	JP04	Chubu Electric Power Co., Inc.	Utilities
	JP05	The Kansai Electric Power Company	Utilities
	JP06	Tokyo Electric Power Company Holdings	Utilities
France	FR01	Veolia Environnement SA	Utilities
Germany	GE01	RWE AG	Utilities
	GE02	E.ON SE	Utilities
Italy	IT01	Eni SpA	Oil & Gas Producers
	IT02	Enel SpA	Utilities
	IT03	Saipem SpA	Oil & Gas Services
	IT04	Snam SpA	Utilities
	IT05	Terna - Rete Elettrica Nazionale	Utilities
	IT06	A2A SpA	Utilities
Norway	NW01	DNO ASA	Oil & Gas Producers
	NW02	Equinor ASA	Oil & Gas Producers
	NW03	Subsea 7 SA	Oil & Gas Services
	NW04	TGS ASA	Oil & Gas Services
Spain	SP01	Iberdrola SA	Utilities
	SP02	Repsol SA	Oil & Gas Producers
	SP03	Endesa SA	Utilities
	SP04	Naturgy Energy Group SA	Utilities
	SP05	Red Electrica Corp SA	Utilities
	SP06	Enagas SA	Utilities
United Kingdom	UK01	BP PLC	Oil & Gas Producers
	UK02	National Grid PLC	Utilities
	UK03	SSE PLC	Utilities
	UK04	DCC PLC	Oil & Gas Producers
	UK05	United Utilities Group PLC	Utilities
	UK06	Severn Trent PLC	Utilities

Source: Bloomberg.

Appendix A2. Statistical description for energy firms stock returns.

Country	ID Code	Mean	Std. Dev.	Min	Max	Skewness	Kurtosis	ADF test
Canada	CA01	0.000	4.39	-37.16	49.66	0.94	17.53	-16.75***
	CA02	0.020	1.84	-31.10	29.75	-1.40	69.36	-17.83***
	CA03	-0.020	2.93	-56.74	19.02	-1.58	37.62	-16.51***
	CA04	0.030	1.98	-19.28	19.38	-0.07	16.52	-16.12***
	CA05	0.003	2.37	-23.14	22.05	-0.43	14.76	-17.37***
	CA06	0.040	1.90	-23.56	14.77	-0.52	18.33	-16.67***
	CA07	0.010	1.48	-18.67	13.20	-0.95	18.65	-17.87***
	CA08	0.010	1.51	-14.56	15.07	-0.59	16.94	-17.84***
	CA09	-0.004	1.94	-63.86	16.71	-8.00	264.60	-15.70***
	CA10	-0.001	1.73	-25.36	16.32	-1.86	37.49	-17.24***
	CA11	0.020	1.09	-12.21	9.44	-0.54	16.26	-17.84***
	CA12	0.020	1.87	-33.84	15.12	-1.93	42.24	-16.78***
	CA13	0.010	1.36	-24.66	18.19	-1.06	41.05	-18.63***
	CA14	0.010	1.98	-19.51	16.08	-0.38	17.13	-17.30***
	CA15	0.030	1.50	-16.80	16.68	-0.22	18.22	-17.98***
	CA16	0.020	2.55	-34.50	20.39	-1.05	23.68	-17.96***
	CA17	0.010	1.32	-19.76	9.93	-0.95	21.28	-18.34***
	CA18	0.020	1.19	-11.55	10.07	-0.07	16.03	-18.57***
	CA19	0.020	1.39	-18.04	17.55	-0.56	26.41	-18.50***
	CA20	-0.020	1.79	-20.21	17.70	-0.10	19.86	-17.20***
	CA21	-0.010	2.81	-52.80	23.02	-1.69	38.21	-17.16***
	CA22	-0.010	2.45	-22.31	23.27	-0.16	10.93	-17.34***
	CA23	-0.020	2.90	-47.13	16.52	-0.87	21.60	-16.50***
	CA24	-0.050	3.49	-68.67	41.99	-0.82	48.15	-17.09***
	CA25	-0.040	3.50	-38.30	60.98	0.62	30.98	-16.86***
	CA26	-0.050	3.48	-60.37	18.23	-1.06	24.93	-16.77***
	CA27	-0.002	3.53	-57.08	26.07	-0.72	23.23	-15.74***
United States	US01	0.010	1.42	-19.09	16.38	-0.67	24.93	-16.93***
	US02	0.020	1.34	-12.31	12.41	-0.08	13.26	-17.02***
	US03	0.004	2.29	-19.00	24.91	0.09	15.75	-15.80***
	US04	-0.010	3.20	-77.36	25.83	-3.28	86.62	-15.77***
	US05	0.030	1.36	-13.11	12.94	-0.30	13.18	-17.03***
	US06	0.020	1.62	-21.99	16.03	-1.06	27.62	-16.90***
	US07	-0.010	3.49	-25.21	24.88	-0.21	9.43	-18.21***
	US08	0.020	2.21	-28.56	22.49	-0.49	17.05	-16.31***
	US09	0.020	1.81	-25.01	20.49	-0.51	25.26	-17.11***
	US10	0.005	1.34	-13.14	15.90	-0.25	18.48	-18.21***
	US11	0.020	1.38	-14.97	12.20	-0.47	19.12	-16.96***
	US12	0.010	1.27	-12.22	12.49	-0.12	16.39	-18.26***
	US13	-0.010	2.89	-46.84	19.45	-0.87	22.47	-16.05***
	US14	0.010	1.20	-14.08	16.56	-0.16	21.61	-17.97***
	US15	0.010	1.59	-14.31	14.31	-0.51	15.98	-16.59***
	US16	0.030	2.57	-38.58	18.57	-0.70	18.45	-17.02***
	US17	0.010	2.69	-20.65	31.71	0.30	12.00	-17.19***
	US18	0.010	1.46	-17.11	13.84	-0.30	17.16	-16.54***
	US19	-0.001	1.62	-17.54	16.55	-0.04	17.61	-17.18***
	US20	-0.010	1.63	-23.45	16.29	-1.12	28.21	-17.63***
	US21	0.020	2.89	-30.48	22.14	-0.42	11.62	-16.32***
	US22	0.003	2.81	-47.23	23.53	-1.39	28.23	-15.47***
	US23	0.030	2.79	-41.05	18.49	-0.88	18.62	-17.20***
	US24	0.004	3.07	-39.95	24.71	-0.70	15.17	-16.20***
	US25	0.010	3.03	-63.21	20.99	-1.82	47.98	-15.09***
	US26	-0.002	3.06	-55.33	23.25	-1.28	31.23	-16.01***
	US27	0.030	1.50	-18.44	15.99	-0.68	17.25	-17.29***
	US28	-0.010	3.03	-34.18	24.16	-0.56	14.46	-16.12***
	US29	0.020	2.39	-19.79	25.76	0.08	17.24	-17.16***
	US30	0.010	1.51	-11.87	15.81	0.03	13.75	-17.80***
	US31	0.010	1.37	-18.03	12.15	-0.67	18.07	-16.87***
	US32	0.000	1.49	-14.75	13.80	-0.62	17.00	-16.96***
	US33	0.030	2.80	-46.08	18.59	-1.18	24.73	-16.09***
	US34	0.003	3.34	-19.48	30.92	0.13	8.00	-18.28***
	US35	0.002	2.47	-32.05	18.16	-0.71	15.42	-15.80***
	US36	0.020	1.23	-12.52	17.20	0.33	23.93	-16.61***
	US37	0.030	1.48	-18.77	14.44	-0.75	25.99	-16.76***

	US38	-0.020	3.50	-34.67	31.24	0.09	9.79	-17.70***
	US39	0.020	2.64	-22.31	27.16	-0.35	12.52	-15.28***
	US40	0.030	1.27	-19.91	12.35	-0.85	25.32	-18.51***
	US41	0.010	2.57	-42.79	29.55	-1.06	36.61	-17.73***
	US42	0.030	1.25	-13.57	10.67	-0.46	14.28	-17.28***
	US43	0.010	1.68	-15.03	15.86	-0.06	13.26	-16.61***
China	CH01	0.010	2.01	-23.65	9.56	-0.41	12.33	-15.89***
	CH02	0.020	2.18	-30.48	9.65	-0.71	16.62	-15.77***
	CH03	0.010	2.41	-21.01	9.63	-0.18	7.95	-16.62***
	CH04	0.010	2.12	-10.59	9.60	-0.26	8.49	-16.05***
	CH05	0.010	2.42	-24.37	9.61	-0.39	9.99	-16.60***
	CH06	0.010	2.44	-15.62	9.62	-0.05	6.83	-16.54***
	CH07	0.020	2.63	-10.64	9.77	0.14	7.38	-16.78***
	CH08	0.020	2.34	-11.21	9.66	-0.18	8.20	-16.74***
	CH09	0.010	2.36	-20.58	9.64	-0.17	8.71	-17.14***
	CH10	0.030	2.76	-10.63	9.65	-0.10	6.77	-16.32***
	CH11	0.020	2.58	-37.73	9.70	-0.76	16.40	-15.81***
	CH12	0.010	2.82	-22.64	9.62	-0.28	6.82	-16.51***
	CH13	0.050	2.82	-11.38	9.66	-0.23	5.84	-15.87***
	CH14	-0.010	2.64	-26.47	9.72	-0.18	9.13	-17.77***
	CH15	0.060	2.46	-30.05	9.63	-0.43	12.38	-16.62***
	CH16	0.020	2.73	-22.37	9.66	-0.34	7.54	-16.86***
	CH17	0.030	2.68	-44.46	9.63	-1.22	22.08	-15.54***
Japan	JP01	0.002	2.43	-21.04	28.36	0.24	13.29	-16.67***
	JP02	0.010	1.56	-12.38	10.60	-0.30	7.73	-17.92***
	JP03	0.010	1.45	-10.91	11.53	0.12	8.08	-18.41***
	JP04	-0.010	1.73	-14.29	12.69	-0.07	9.10	-18.44***
	JP05	-0.010	1.98	-15.95	16.25	0.07	10.17	-17.16***
	JP06	-0.030	2.94	-29.47	28.44	0.31	25.40	-15.11***
France	FR01	-0.004	1.97	-23.96	16.71	-0.84	16.35	-15.81***
Germany	GE01	-0.010	1.96	-19.66	15.24	-0.41	11.21	-16.66***
	GE02	-0.020	1.75	-12.27	16.19	-0.29	10.39	-16.84***
Italy	IT01	-0.010	1.77	-23.39	15.71	-0.55	20.11	-18.07***
	IT02	0.003	1.69	-22.12	16.82	-0.77	14.94	-16.22***
	IT03	-0.070	3.41	-66.48	52.85	-3.04	80.86	-17.22***
	IT04	0.010	1.35	-21.30	9.53	-1.36	21.33	-17.95***
	IT05	0.030	1.34	-16.19	9.50	-0.83	13.75	-18.68***
	IT06	0.004	1.88	-21.12	12.55	-0.44	10.29	-16.07***
Norway	NW01	-0.010	3.61	-61.32	31.10	-0.76	26.85	-16.83***
	NW02	0.020	1.94	-19.50	12.74	-0.31	8.46	-17.57***
	NW03	0.010	2.72	-23.73	17.30	-0.37	8.58	-17.34***
	NW04	0.010	2.92	-31.64	20.43	-0.29	11.25	-17.63***
Spain	SP01	0.020	1.68	-15.16	17.23	0.06	15.49	-16.97***
	SP02	-0.010	2.01	-17.14	16.74	-0.14	10.51	-16.91***
	SP03	-0.003	1.88	-65.41	12.12	-10.35	334.84	-16.34***
	SP04	0.010	1.68	-18.26	14.40	-0.37	11.47	-15.67***
	SP05	-0.010	2.47	-137.54	13.68	-36.98	208.45	-16.77***
	SP06	0.001	1.47	-16.02	13.80	-0.63	11.51	-16.95***
United Kingdom	UK01	-0.010	1.84	-21.67	19.54	-0.20	15.05	-17.28***
	UK02	0.010	1.31	-10.19	15.33	-0.41	14.24	-17.29***
	UK03	0.010	1.46	-12.98	13.47	-0.53	13.26	-17.31***
	UK04	0.030	1.66	-11.95	12.58	0.12	8.55	-17.51***
	UK05	0.005	1.43	-28.32	10.81	-1.76	39.19	-17.48***
	UK06	0.010	1.41	-16.05	15.17	-0.20	14.31	-17.26***

Notes: Statistics are in percentage points. Data correspond to the return for an equally-weighted portfolio for each country or sector. The sampled period extends from January 3, 2006, to December 15, 2023. ADF corresponds to the Augmented Dickey-Fuller unit root test. This test only considers the random walk specification. Superscripts ***, **, * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. Source: Authors.

Appendix A3. Spillover decomposition between energy stock and fuel markets: country-sector level.

Sector	ID code	Total spillover index			Specific-market spillover (internal)			Cross-market spillover (external)		
		To other	From others	Net	To other	From others	Net	To other	From others	Net
<i>A. 95th quantile of return's distribution</i>										
Utilities	CA.UT	91.6	94.4	-2.8	84.1	86.8	-2.6	7.4	7.7	-0.2
Utilities	US.UT	95.0	94.1	0.9	87.2	86.3	0.9	7.8	7.7	0.1
Utilities	CH.UT	89.7	94.0	-4.3	82.1	86.2	-4.1	7.6	7.7	-0.2
Utilities	JP.UT	89.4	94.2	-4.8	81.8	86.2	-4.4	7.6	8.1	-0.5
Utilities	FR.UT	93.7	94.2	-0.5	86.2	86.7	-0.5	7.5	7.5	0.0
Utilities	GE.UT	95.8	94.3	1.4	88.1	86.8	1.3	7.7	7.5	0.2
Utilities	IT.UT	95.4	94.4	1.0	87.8	87.0	0.8	7.6	7.4	0.2
Utilities	SP.UT	92.9	94.3	-1.4	85.5	87.0	-1.4	7.4	7.3	0.0
Utilities	UK.UT	92.3	94.3	-2.0	84.9	86.8	-1.9	7.4	7.6	-0.1
Renewables energies	CA.RE	89.9	94.2	-4.3	82.3	86.3	-4.0	7.6	7.9	-0.3
Renewables energies	JP.RE	92.0	94.1	-2.1	84.1	86.1	-2.0	7.8	7.9	-0.1
Oil and Gas Services	CA.OS	99.2	94.2	5.0	90.7	86.2	4.5	8.5	8.0	0.5
Oil and Gas Services	US.OS	98.0	94.5	3.5	89.7	86.5	3.2	8.3	8.0	0.3
Oil and Gas Services	CH.OS	89.0	94.4	-5.4	81.5	86.4	-4.9	7.5	8.0	-0.5
Oil and Gas Services	IT.OS	91.8	94.4	-2.6	84.2	86.6	-2.4	7.6	7.8	-0.2
Oil and Gas Services	NW.OS	95.4	94.5	0.9	87.4	86.6	0.7	8.0	7.8	0.1
Oil and Gas Producers	CA.OP	99.0	94.5	4.5	90.7	86.5	4.2	8.3	8.0	0.4
Oil and Gas Producers	US.OP	99.9	94.5	5.4	91.4	86.4	5.0	8.4	8.1	0.4
Oil and Gas Producers	CH.OP	89.2	94.2	-5.0	81.7	86.3	-4.6	7.5	7.9	-0.4
Oil and Gas Producers	IT.OP	97.0	94.6	2.4	89.1	87.0	2.1	7.9	7.7	0.3
Oil and Gas Producers	NW.OP	96.1	94.4	1.7	88.0	86.5	1.5	8.1	7.9	0.2
Oil and Gas Producers	SP.OP	99.2	94.5	4.7	91.0	86.8	4.3	8.1	7.7	0.4
Oil and Gas Producers	UK.OP	99.1	94.3	4.8	90.9	86.6	4.3	8.2	7.8	0.5
Fuel markets	NGAS	88.6	93.8	-5.2	3.8	4.2	-0.4	84.8	89.6	-4.8
Fuel markets	OIL	98.3	94.1	4.2	4.2	3.8	0.4	94.1	90.3	3.8
Full system		94.3	94.3	0.0	79.9	79.9	0.0	14.4	14.4	0.0
Utilities		92.9	94.2	-1.4	85.3	86.6	-1.3	7.5	7.6	-0.1
Renewables energies		90.9	94.2	-3.2	83.2	86.2	-3.0	7.7	7.9	-0.2
Oil and Gas Services		94.6	94.4	0.3	86.7	86.4	0.2	8.0	7.9	0.0
Oil and Gas Producers		97.1	94.4	2.7	89.0	86.6	2.4	8.1	7.9	0.2
Fuel markets		93.4	93.9	-0.5	4.0	4.0	0.0	89.5	90.0	-0.5
<i>B. 50th quantile of return's distribution</i>										
Sector	ID code	To other	From others	Net	To other	From others	Net	To other	From others	Net
Utilities	CA.UT	68.8	66.6	2.1	66.2	64.4	1.7	2.6	2.2	0.4
Utilities	US.UT	57.7	61.1	-3.5	55.5	59.3	-3.8	2.2	1.9	0.4
Utilities	CH.UT	42.8	49.9	-7.1	41.6	48.8	-7.1	1.1	1.1	0.0
Utilities	JP.UT	15.7	44.8	-29.2	14.6	43.3	-28.7	1.1	1.6	-0.5
Utilities	FR.UT	60.6	66.7	-6.1	58.7	65.2	-6.5	1.9	1.6	0.4
Utilities	GE.UT	71.3	69.5	1.7	69.0	67.7	1.2	2.3	1.8	0.5
Utilities	IT.UT	84.4	74.5	9.9	82.1	73.1	9.0	2.4	1.5	0.9
Utilities	SP.UT	79.6	72.0	7.6	77.7	70.6	7.0	1.9	1.3	0.6
Utilities	UK.UT	54.9	65.2	-10.2	53.7	63.7	-10.1	1.2	1.4	-0.2
Renewables energies	CA.RE	29.3	46.7	-17.4	27.9	45.1	-17.1	1.4	1.6	-0.3
Renewables energies	JP.RE	18.5	49.4	-30.9	17.3	47.8	-30.5	1.2	1.7	-0.5
Oil and Gas Services	CA.OS	79.0	74.5	4.5	71.3	68.5	2.8	7.7	6.0	1.7
Oil and Gas Services	US.OS	107.9	79.8	28.1	97.7	73.3	24.4	10.1	6.5	3.6
Oil and Gas Services	CH.OS	38.9	52.0	-13.1	37.7	50.1	-12.4	1.2	1.9	-0.7
Oil and Gas Services	IT.OS	66.7	68.3	-1.7	62.4	64.8	-2.4	4.3	3.5	0.8
Oil and Gas Services	NW.OS	69.1	73.5	-4.4	64.8	69.7	-4.9	4.3	3.8	0.5
Oil and Gas Producers	CA.OP	107.5	79.7	27.9	97.1	73.1	24.0	10.4	6.6	3.9
Oil and Gas Producers	US.OP	113.8	80.4	33.4	103.1	73.7	29.4	10.7	6.7	4.0
Oil and Gas Producers	CH.OP	46.8	55.7	-8.9	45.7	53.9	-8.2	1.1	1.8	-0.7
Oil and Gas Producers	IT.OP	104.2	80.0	24.2	99.0	76.7	22.3	5.2	3.3	1.9
Oil and Gas Producers	NW.OP	67.1	72.4	-5.3	62.0	68.2	-6.2	5.1	4.2	0.9
Oil and Gas Producers	SP.OP	93.4	78.3	15.1	88.4	75.0	13.4	5.0	3.3	1.7
Oil and Gas Producers	UK.OP	77.7	74.4	3.3	73.7	71.2	2.5	4.0	3.2	0.8
Fuel markets	NGAS	10.1	21.4	-11.4	0.5	1.1	-0.6	9.6	20.3	-10.8
Fuel markets	OIL	60.0	68.7	-8.6	1.1	0.5	0.6	58.9	68.2	-9.2
Full system		65.0	65.0	0.0	58.7	58.7	0.0	6.3	6.3	0.0
Utilities		59.5	63.4	-3.9	57.7	61.8	-4.1	1.9	1.6	0.3
Renewables energies		23.9	48.1	-24.2	22.6	46.4	-23.8	1.3	1.6	-0.4
Oil and Gas Services		72.3	69.6	2.7	66.8	65.3	1.5	5.5	4.4	1.2
Oil and Gas Producers		87.2	74.4	12.8	81.3	70.2	11.0	5.9	4.2	1.8
Fuel markets		35.0	45.1	-10.0	0.8	0.8	0.0	34.2	44.3	-10.0

<i>C. 5th quantile of return's distribution</i>										
Sector	ID code	To other	From others	Net	To other	From others	Net	To other	From others	Net
Utilities	CA.UT	99.7	94.7	5.0	91.4	87.1	4.3	8.2	7.6	0.6
Utilities	US.UT	98.5	94.6	3.8	90.3	87.1	3.3	8.1	7.6	0.6
Utilities	CH.UT	92.8	94.6	-1.9	84.9	87.1	-2.1	7.8	7.6	0.2
Utilities	JP.UT	86.7	95.0	-8.3	79.5	87.4	-7.9	7.2	7.6	-0.4
Utilities	FR.UT	94.3	94.8	-0.5	86.6	87.3	-0.7	7.7	7.5	0.2
Utilities	GE.UT	97.6	94.7	2.8	89.6	87.3	2.4	7.9	7.5	0.5
Utilities	IT.UT	95.9	94.9	1.0	88.1	87.5	0.6	7.8	7.4	0.4
Utilities	SP.UT	94.2	94.8	-0.6	86.6	87.3	-0.8	7.6	7.5	0.1
Utilities	UK.UT	94.8	94.8	0.1	87.1	87.4	-0.2	7.7	7.4	0.3
Renewables energies	CA.RE	89.3	94.6	-5.3	81.8	86.9	-5.1	7.5	7.7	-0.2
Renewables energies	JP.RE	85.1	95.2	-10.1	78.0	87.4	-9.4	7.1	7.7	-0.7
Oil and Gas Services	CA.OS	97.3	94.7	2.6	89.0	86.9	2.1	8.3	7.8	0.5
Oil and Gas Services	US.OS	100.5	94.8	5.7	92.1	87.1	5.0	8.4	7.7	0.7
Oil and Gas Services	CH.OS	88.6	94.8	-6.2	81.1	87.1	-6.0	7.4	7.7	-0.2
Oil and Gas Services	IT.OS	93.4	94.8	-1.5	85.6	87.2	-1.5	7.7	7.6	0.1
Oil and Gas Services	NW.OS	97.5	94.9	2.6	89.3	87.2	2.1	8.2	7.7	0.5
Oil and Gas Producers	CA.OP	101.4	94.8	6.5	92.8	87.1	5.8	8.6	7.8	0.8
Oil and Gas Producers	US.OP	101.8	94.8	7.0	93.2	87.1	6.1	8.6	7.8	0.8
Oil and Gas Producers	CH.OP	94.1	94.7	-0.6	86.2	87.0	-0.8	7.9	7.7	0.2
Oil and Gas Producers	IT.OP	97.1	95.1	2.1	89.3	87.5	1.8	7.8	7.5	0.3
Oil and Gas Producers	NW.OP	95.4	94.9	0.5	87.4	87.3	0.2	8.0	7.6	0.3
Oil and Gas Producers	SP.OP	96.2	95.0	1.2	88.3	87.4	0.8	7.9	7.6	0.3
Oil and Gas Producers	UK.OP	95.3	95.0	0.3	87.5	87.4	0.1	7.8	7.6	0.2
Fuel markets	NGAS	83.2	94.5	-11.3	3.5	4.2	-0.7	79.7	90.3	-10.6
Fuel markets	OIL	99.5	94.6	4.9	4.2	3.5	0.7	95.3	91.1	4.3
Full system		94.8	94.8	0.0	80.5	80.5	0.0	14.3	14.3	0.0
Utilities		94.9	94.8	0.2	87.1	87.3	-0.1	7.8	7.5	0.3
Renewables energies		87.2	94.9	-7.7	79.9	87.1	-7.3	7.3	7.7	-0.4
Oil and Gas Services		95.4	94.8	0.6	87.4	87.1	0.3	8.0	7.7	0.3
Oil and Gas Producers		97.3	94.9	2.4	89.2	87.2	2.0	8.1	7.7	0.4
Fuel markets		91.4	94.6	-3.2	3.9	3.9	0.0	87.5	90.7	-3.2

Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPPS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. We use a classification of $q = 2$ groups or markets, defined as fuel (natural gas and oil) and energy stock markets. Source: Authors.

Appendix A4. Spillover decomposition between energy firms and fuel markets: 95th quantile.

Country	ID code	Total spillover index			Specific-market spillover (internal)			Cross-market spillover (external)		
		To other	From others	Net	To other	From others	Net	To other	From others	Net
Canada	CA01	102.4	99.1	3.3	100.7	97.3	3.4	1.7	1.8	-0.1
	CA02	96.8	99.2	-2.3	95.2	97.4	-2.2	1.6	1.8	-0.2
	CA03	101.1	99.1	2.0	99.4	97.3	2.0	1.7	1.8	-0.1
	CA04	98.2	99.2	-0.9	96.6	97.4	-0.8	1.6	1.8	-0.1
	CA05	97.8	99.2	-1.4	96.1	97.4	-1.3	1.7	1.8	-0.1
	CA06	98.5	99.1	-0.6	96.9	97.4	-0.5	1.7	1.8	-0.1
	CA07	94.7	99.2	-4.4	93.1	97.4	-4.3	1.6	1.8	-0.2
	CA08	95.2	99.2	-4.0	93.6	97.4	-3.8	1.6	1.8	-0.2
	CA09	99.2	99.1	0.1	97.5	97.4	0.2	1.7	1.8	-0.1
	CA10	95.2	99.2	-3.9	93.6	97.4	-3.8	1.6	1.8	-0.1
	CA11	95.0	99.2	-4.2	93.3	97.4	-4.1	1.6	1.8	-0.2
	CA12	94.8	99.2	-4.4	93.2	97.4	-4.2	1.6	1.8	-0.2
	CA13	98.5	99.2	-0.7	96.8	97.4	-0.6	1.7	1.8	-0.1
	CA14	98.4	99.2	-0.7	96.8	97.4	-0.6	1.7	1.8	-0.1
	CA15	98.5	99.2	-0.7	96.8	97.4	-0.5	1.6	1.8	-0.1
	CA16	101.4	99.1	2.3	99.7	97.3	2.4	1.7	1.8	-0.1
	CA17	93.1	99.2	-6.1	91.6	97.4	-5.9	1.6	1.8	-0.2
	CA18	100.1	99.1	0.9	98.4	97.3	1.1	1.7	1.8	-0.1
	CA19	95.5	99.2	-3.7	93.9	97.4	-3.5	1.6	1.8	-0.2
	CA20	99.2	99.1	0.0	97.5	97.4	0.2	1.7	1.8	-0.1
	CA21	96.0	99.2	-3.2	94.4	97.4	-3.0	1.6	1.8	-0.2
	CA22	96.7	99.1	-2.4	95.1	97.4	-2.2	1.6	1.8	-0.2
	CA23	100.0	99.1	0.9	98.4	97.3	1.0	1.7	1.8	-0.1
	CA24	100.1	99.1	0.9	98.4	97.4	1.0	1.7	1.8	-0.1
	CA25	100.4	99.1	1.3	98.7	97.3	1.4	1.7	1.8	-0.1
	CA26	105.5	99.1	6.4	103.8	97.3	6.5	1.8	1.8	0.0
	CA27	100.4	99.1	1.3	98.7	97.3	1.4	1.7	1.8	-0.1
United States	US01	101.7	99.1	2.5	100.0	97.3	2.6	1.7	1.8	-0.1
	US02	101.4	99.1	2.3	99.7	97.4	2.4	1.7	1.8	-0.1
	US03	98.3	99.1	-0.8	96.7	97.3	-0.7	1.7	1.8	-0.2
	US04	102.8	99.1	3.7	101.1	97.3	3.8	1.7	1.8	-0.1
	US05	102.0	99.1	2.8	100.2	97.3	2.9	1.7	1.8	-0.1
	US06	96.9	99.2	-2.3	95.2	97.4	-2.2	1.6	1.8	-0.1
	US07	98.2	99.2	-0.9	96.6	97.4	-0.8	1.6	1.8	-0.2
	US08	100.7	99.1	1.5	99.0	97.3	1.7	1.7	1.8	-0.1
	US09	98.6	99.2	-0.6	96.9	97.4	-0.5	1.7	1.8	-0.1
	US10	99.1	99.1	-0.1	97.4	97.4	0.0	1.7	1.8	-0.1
	US11	103.6	99.1	4.5	101.8	97.3	4.5	1.7	1.8	-0.1
	US12	104.6	99.1	5.5	102.8	97.3	5.5	1.8	1.8	0.0
	US13	107.2	99.1	8.1	105.4	97.3	8.1	1.8	1.8	0.0
	US14	102.5	99.1	3.4	100.8	97.3	3.5	1.7	1.8	-0.1
	US15	100.3	99.1	1.1	98.6	97.3	1.2	1.7	1.8	-0.1
	US16	103.9	99.1	4.7	102.1	97.3	4.8	1.8	1.8	-0.1
	US17	99.8	99.1	0.7	98.1	97.3	0.8	1.7	1.8	-0.1
	US18	98.3	99.2	-0.9	96.7	97.4	-0.7	1.6	1.8	-0.1
	US19	100.8	99.1	1.7	99.1	97.3	1.7	1.7	1.8	-0.1
	US20	99.0	99.2	-0.2	97.3	97.4	0.0	1.7	1.8	-0.1
	US21	103.4	99.1	4.3	101.6	97.3	4.3	1.7	1.8	-0.1
	US22	102.3	99.1	3.2	100.6	97.3	3.2	1.7	1.8	-0.1
	US23	99.7	99.1	0.6	98.0	97.3	0.7	1.7	1.8	-0.1
	US24	101.6	99.1	2.5	99.9	97.4	2.5	1.7	1.8	-0.1
	US25	106.7	99.1	7.7	105.0	97.3	7.7	1.8	1.8	0.0
	US26	102.4	99.1	3.3	100.7	97.3	3.4	1.7	1.8	-0.1
	US27	96.2	99.2	-2.9	94.6	97.4	-2.8	1.6	1.8	-0.2
	US28	101.6	99.1	2.4	99.9	97.4	2.6	1.7	1.8	-0.1
	US29	99.7	99.1	0.6	98.1	97.4	0.7	1.7	1.8	-0.1
	US30	100.1	99.1	0.9	98.4	97.4	1.0	1.7	1.8	-0.1
	US31	102.0	99.1	2.9	100.3	97.3	3.0	1.7	1.8	-0.1
	US32	97.5	99.2	-1.7	95.9	97.3	-1.5	1.6	1.8	-0.2
	US33	105.9	99.1	6.9	104.1	97.3	6.9	1.8	1.8	0.0
	US34	100.3	99.1	1.1	98.6	97.4	1.2	1.7	1.8	-0.1
	US35	101.6	99.1	2.4	99.8	97.3	2.5	1.7	1.8	-0.1
	US36	102.8	99.1	3.7	101.1	97.3	3.8	1.7	1.8	-0.1
	US37	100.1	99.1	1.0	98.4	97.3	1.1	1.7	1.8	-0.1

	US38	102.9	99.1	3.8	101.2	97.3	3.8	1.7	1.8	-0.1
	US39	100.9	99.1	1.8	99.2	97.3	1.9	1.7	1.8	-0.1
	US40	104.7	99.1	5.6	102.9	97.3	5.6	1.7	1.8	0.0
	US41	103.0	99.1	3.9	101.3	97.3	4.0	1.7	1.8	-0.1
	US42	103.9	99.1	4.8	102.2	97.3	4.8	1.7	1.8	0.0
	US43	99.3	99.1	0.1	97.6	97.3	0.3	1.7	1.8	-0.1
China	CH01	99.1	99.1	0.0	97.5	97.4	0.1	1.7	1.8	-0.1
	CH02	97.4	99.1	-1.8	95.8	97.3	-1.6	1.6	1.8	-0.2
	CH03	97.3	99.2	-1.9	95.7	97.4	-1.7	1.6	1.8	-0.2
	CH04	102.0	99.1	2.8	100.2	97.3	2.9	1.7	1.8	-0.1
	CH05	99.9	99.1	0.8	98.2	97.3	0.9	1.7	1.8	-0.1
	CH06	97.9	99.2	-1.3	96.3	97.4	-1.1	1.6	1.8	-0.2
	CH07	101.3	99.1	2.2	99.6	97.3	2.3	1.7	1.8	-0.1
	CH08	99.8	99.1	0.7	98.1	97.4	0.8	1.7	1.8	-0.1
	CH09	99.7	99.1	0.6	98.0	97.4	0.7	1.7	1.8	-0.1
	CH10	99.0	99.1	-0.2	97.3	97.4	0.0	1.7	1.8	-0.1
	CH11	100.1	99.1	1.0	98.5	97.3	1.1	1.7	1.8	-0.1
	CH12	94.1	99.2	-5.1	92.5	97.4	-4.9	1.6	1.8	-0.2
	CH13	96.6	99.2	-2.6	95.0	97.4	-2.4	1.6	1.8	-0.2
	CH14	99.0	99.1	-0.1	97.3	97.4	0.0	1.7	1.8	-0.1
	CH15	93.4	99.2	-5.8	91.8	97.4	-5.6	1.6	1.8	-0.2
	CH16	100.2	99.1	1.1	98.5	97.3	1.2	1.7	1.8	-0.1
	CH17	97.9	99.1	-1.2	96.3	97.4	-1.1	1.6	1.8	-0.1
Japan	JP01	97.2	99.2	-1.9	95.6	97.3	-1.8	1.6	1.8	-0.2
	JP02	98.0	99.2	-1.1	96.3	97.4	-1.0	1.7	1.8	-0.1
	JP03	101.3	99.1	2.2	99.6	97.3	2.2	1.7	1.8	-0.1
	JP04	98.6	99.1	-0.5	96.9	97.3	-0.4	1.7	1.8	-0.1
	JP05	101.3	99.1	2.2	99.5	97.3	2.2	1.7	1.8	-0.1
	JP06	102.0	99.1	2.9	100.3	97.3	3.0	1.7	1.8	-0.1
France	FR01	94.4	99.2	-4.7	92.9	97.4	-4.6	1.6	1.8	-0.2
Germany	GE01	95.8	99.2	-3.4	94.2	97.4	-3.2	1.6	1.8	-0.2
	GE02	98.4	99.2	-0.7	96.8	97.4	-0.6	1.7	1.8	-0.1
Italy	IT01	96.5	99.2	-2.7	94.9	97.4	-2.5	1.6	1.8	-0.2
	IT02	94.7	99.2	-4.4	93.1	97.4	-4.2	1.6	1.8	-0.2
	IT03	94.2	99.2	-5.0	92.6	97.4	-4.8	1.6	1.8	-0.2
	IT04	93.8	99.2	-5.4	92.3	97.4	-5.2	1.6	1.8	-0.2
	IT05	96.4	99.2	-2.8	94.7	97.4	-2.6	1.6	1.8	-0.2
	IT06	98.8	99.2	-0.4	97.1	97.4	-0.3	1.7	1.8	-0.1
Norway	NW01	99.2	99.1	0.1	97.6	97.3	0.2	1.7	1.8	-0.1
	NW02	94.2	99.2	-4.9	92.7	97.4	-4.7	1.6	1.8	-0.2
	NW03	96.8	99.2	-2.4	95.2	97.4	-2.2	1.6	1.8	-0.2
	NW04	97.9	99.2	-1.3	96.2	97.4	-1.2	1.7	1.8	-0.1
Spain	SP01	97.9	99.1	-1.2	96.3	97.4	-1.1	1.6	1.8	-0.2
	SP02	94.9	99.2	-4.3	93.3	97.4	-4.2	1.6	1.8	-0.2
	SP03	86.9	99.3	-12.3	85.5	97.5	-12.0	1.4	1.8	-0.3
	SP04	95.7	99.2	-3.4	94.1	97.4	-3.2	1.6	1.8	-0.2
	SP05	93.8	99.2	-5.4	92.3	97.4	-5.1	1.6	1.8	-0.2
	SP06	97.6	99.2	-1.5	96.0	97.4	-1.4	1.6	1.8	-0.2
United Kingdom	UK01	97.3	99.2	-1.9	95.7	97.4	-1.7	1.6	1.8	-0.2
	UK02	93.4	99.2	-5.8	91.9	97.4	-5.5	1.5	1.8	-0.3
	UK03	94.8	99.2	-4.3	93.3	97.4	-4.1	1.6	1.8	-0.2
	UK04	98.3	99.1	-0.9	96.6	97.3	-0.7	1.7	1.8	-0.1
	UK05	100.2	99.1	1.1	98.5	97.3	1.2	1.7	1.8	-0.1
	UK06	98.6	99.2	-0.6	96.9	97.3	-0.4	1.7	1.8	-0.1
Fuels	NGAS	108.2	99.1	9.1	0.9	0.9	0.0	107.3	98.2	9.1
	OIL	104.6	99.1	5.4	0.9	0.9	0.0	103.7	98.2	5.5
Average spillover		99.1	99.1	0.0	95.7	95.7	0.0	3.4	3.4	0.0

Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPSS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. We use a classification of $q = 2$ groups or markets, defined as fuel (natural gas and oil) and energy stock markets. Source: Authors.

Appendix A5. Spillover decomposition between energy firms and fuel markets: 50th quantile.

Country	ID code	Total spillover index			Specific-market spillover (internal)			Cross-market spillover (external)		
		To other	From others	Net	To other	From others	Net	To other	From others	Net
Canada	CA01	83.6	98.9	-15.3	82.2	97.3	-15.2	1.4	1.6	-0.2
	CA02	100.8	98.9	1.9	99.1	97.3	1.7	1.7	1.6	0.1
	CA03	104.7	98.8	5.9	103.0	97.3	5.7	1.8	1.6	0.2
	CA04	86.4	99.0	-12.6	84.9	97.4	-12.5	1.5	1.6	-0.1
	CA05	110.7	98.8	11.9	108.9	97.3	11.6	1.9	1.6	0.3
	CA06	88.6	99.0	-10.4	87.1	97.4	-10.3	1.5	1.6	-0.1
	CA07	93.5	99.0	-5.5	91.9	97.4	-5.5	1.6	1.5	0.0
	CA08	92.3	98.9	-6.6	90.7	97.3	-6.6	1.6	1.6	0.0
	CA09	95.3	98.9	-3.7	93.7	97.4	-3.7	1.6	1.6	0.0
	CA10	94.2	98.9	-4.7	92.6	97.4	-4.7	1.6	1.6	0.0
	CA11	94.1	98.9	-4.8	92.5	97.4	-4.9	1.6	1.5	0.0
	CA12	92.1	99.0	-6.9	90.5	97.4	-6.9	1.6	1.6	0.0
	CA13	100.2	98.9	1.3	98.5	97.3	1.2	1.7	1.6	0.1
	CA14	105.0	98.9	6.1	103.2	97.3	5.9	1.8	1.6	0.2
	CA15	90.1	98.9	-8.8	88.6	97.4	-8.8	1.5	1.6	-0.1
	CA16	109.7	98.8	10.8	107.8	97.3	10.5	1.9	1.6	0.3
	CA17	98.7	98.9	-0.3	97.0	97.4	-0.4	1.7	1.6	0.1
	CA18	98.5	98.9	-0.4	96.9	97.3	-0.5	1.6	1.6	0.1
	CA19	102.4	98.9	3.5	100.7	97.3	3.3	1.7	1.5	0.2
	CA20	92.7	98.9	-6.3	91.1	97.4	-6.3	1.6	1.6	0.0
	CA21	104.8	98.9	6.0	103.1	97.3	5.7	1.8	1.6	0.2
	CA22	103.1	98.9	4.2	101.4	97.3	4.0	1.7	1.5	0.2
	CA23	105.6	98.8	6.8	103.8	97.3	6.5	1.8	1.6	0.2
	CA24	99.6	98.9	0.6	97.9	97.4	0.5	1.7	1.6	0.1
	CA25	95.8	98.9	-3.1	94.2	97.4	-3.2	1.6	1.6	0.1
	CA26	99.8	98.9	0.9	98.1	97.4	0.8	1.7	1.6	0.1
	CA27	95.7	98.9	-3.3	94.0	97.4	-3.3	1.6	1.6	0.1
United States	US01	111.9	98.8	13.1	110.0	97.3	12.7	1.9	1.5	0.3
	US02	111.4	98.8	12.6	109.5	97.3	12.2	1.9	1.5	0.3
	US03	102.5	98.9	3.6	100.8	97.4	3.4	1.7	1.5	0.2
	US04	109.0	98.9	10.1	107.1	97.3	9.8	1.8	1.6	0.3
	US05	112.8	98.8	14.0	110.9	97.3	13.7	1.9	1.5	0.3
	US06	103.1	98.9	4.2	101.4	97.4	4.0	1.7	1.5	0.2
	US07	98.3	99.0	-0.7	96.6	97.4	-0.8	1.7	1.6	0.1
	US08	118.9	98.8	20.2	116.9	97.2	19.7	2.0	1.6	0.4
	US09	111.6	98.8	12.8	109.7	97.3	12.4	1.9	1.6	0.3
	US10	105.2	98.9	6.4	103.5	97.4	6.1	1.8	1.5	0.2
	US11	108.9	98.9	10.0	107.1	97.3	9.7	1.8	1.5	0.3
	US12	108.1	98.8	9.2	106.3	97.3	9.0	1.8	1.5	0.3
	US13	119.0	98.8	20.3	117.0	97.2	19.8	2.0	1.6	0.4
	US14	108.8	98.8	10.0	107.0	97.3	9.7	1.8	1.5	0.3
	US15	104.6	98.8	5.7	102.8	97.3	5.5	1.8	1.5	0.2
	US16	110.0	98.9	11.1	108.1	97.3	10.8	1.9	1.6	0.3
	US17	103.1	98.9	4.2	101.4	97.4	4.0	1.7	1.5	0.2
	US18	102.1	98.9	3.2	100.5	97.4	3.1	1.7	1.5	0.2
	US19	106.5	98.9	7.6	104.7	97.3	7.4	1.8	1.5	0.2
	US20	100.5	98.9	1.6	98.9	97.4	1.5	1.7	1.6	0.1
	US21	103.8	98.9	4.9	102.0	97.3	4.7	1.7	1.6	0.2
	US22	111.0	98.8	12.1	109.1	97.3	11.8	1.9	1.6	0.3
	US23	111.4	98.9	12.5	109.5	97.3	12.2	1.9	1.6	0.3
	US24	108.1	98.9	9.3	106.3	97.3	9.0	1.8	1.6	0.3
	US25	115.4	98.8	16.5	113.4	97.2	16.2	1.9	1.6	0.4
	US26	110.7	98.8	11.9	108.8	97.2	11.6	1.9	1.6	0.3
	US27	104.1	98.9	5.3	102.4	97.4	5.1	1.7	1.5	0.2
	US28	106.9	98.9	8.0	105.1	97.3	7.8	1.8	1.6	0.2
	US29	95.6	98.9	-3.4	93.9	97.4	-3.4	1.6	1.6	0.0
	US30	105.8	98.9	6.9	104.1	97.3	6.7	1.8	1.5	0.2
	US31	108.9	98.9	10.1	107.1	97.3	9.8	1.8	1.5	0.3
	US32	101.4	98.9	2.5	99.8	97.4	2.4	1.7	1.5	0.2
	US33	106.0	98.9	7.2	104.2	97.3	6.9	1.8	1.6	0.2
	US34	104.9	98.9	6.0	103.2	97.3	5.9	1.8	1.6	0.2
	US35	107.1	98.9	8.2	105.3	97.3	8.0	1.8	1.6	0.2

	US36	102.5	98.9	3.6	100.8	97.3	3.5	1.7	1.5	0.2
	US37	108.1	98.8	9.2	106.3	97.3	9.0	1.8	1.5	0.3
	US38	98.8	98.9	-0.1	97.2	97.4	-0.2	1.7	1.6	0.1
	US39	102.9	98.9	4.0	101.2	97.3	3.9	1.7	1.6	0.2
	US40	113.1	98.8	14.3	111.2	97.3	14.0	1.9	1.5	0.3
	US41	101.4	98.9	2.4	99.6	97.4	2.3	1.7	1.6	0.2
	US42	115.3	98.8	16.5	113.4	97.3	16.1	1.9	1.5	0.4
	US43	107.8	98.9	8.9	106.0	97.3	8.6	1.8	1.6	0.2
China	CH01	85.9	99.0	-13.1	84.4	97.4	-13.0	1.5	1.6	-0.1
	CH02	89.4	98.9	-9.5	87.9	97.4	-9.5	1.5	1.6	-0.1
	CH03	84.4	99.0	-14.7	83.0	97.5	-14.5	1.4	1.5	-0.1
	CH04	88.2	99.0	-10.8	86.7	97.5	-10.7	1.5	1.5	-0.1
	CH05	86.7	99.0	-12.3	85.2	97.4	-12.2	1.5	1.5	-0.1
	CH06	84.7	99.0	-14.3	83.3	97.5	-14.2	1.4	1.6	-0.1
	CH07	87.7	98.9	-11.3	86.2	97.4	-11.2	1.5	1.5	-0.1
	CH08	83.5	99.0	-15.5	82.1	97.5	-15.4	1.4	1.6	-0.2
	CH09	87.6	99.0	-11.3	86.2	97.4	-11.3	1.5	1.6	-0.1
	CH10	89.2	99.0	-9.8	87.7	97.4	-9.8	1.5	1.6	-0.1
	CH11	86.2	98.9	-12.8	84.7	97.4	-12.7	1.4	1.6	-0.1
	CH12	82.3	99.1	-16.7	80.9	97.5	-16.6	1.4	1.6	-0.2
	CH13	84.3	99.0	-14.8	82.9	97.5	-14.6	1.4	1.6	-0.1
	CH14	88.3	98.9	-10.6	86.8	97.4	-10.6	1.5	1.6	-0.1
	CH15	86.0	99.0	-13.0	84.6	97.4	-12.9	1.5	1.5	-0.1
	CH16	84.0	99.0	-15.0	82.6	97.4	-14.8	1.4	1.6	-0.2
	CH17	86.7	99.0	-12.3	85.3	97.5	-12.2	1.4	1.6	-0.1
Japan	JP01	83.4	99.0	-15.6	82.0	97.5	-15.4	1.4	1.6	-0.2
	JP02	90.8	99.0	-8.2	89.3	97.4	-8.1	1.5	1.6	0.0
	JP03	94.8	98.9	-4.1	93.2	97.4	-4.2	1.6	1.6	0.0
	JP04	92.4	98.9	-6.6	90.8	97.4	-6.6	1.5	1.6	0.0
	JP05	89.9	99.0	-9.0	88.4	97.4	-9.0	1.5	1.6	-0.1
	JP06	89.5	98.9	-9.4	88.0	97.3	-9.3	1.5	1.6	0.0
France	FR01	93.0	98.9	-5.9	91.5	97.4	-5.9	1.5	1.6	0.0
Germany	GE01	97.9	98.9	-1.0	96.3	97.4	-1.1	1.6	1.6	0.1
	GE02	101.5	98.9	2.7	99.8	97.3	2.5	1.7	1.6	0.1
Italy	IT01	114.1	98.8	15.2	112.1	97.3	14.9	1.9	1.6	0.4
	IT02	105.8	98.9	6.9	104.0	97.3	6.7	1.8	1.6	0.2
	IT03	101.7	98.8	3.0	100.0	97.2	2.8	1.7	1.6	0.2
	IT04	97.3	98.9	-1.7	95.6	97.4	-1.7	1.6	1.5	0.1
	IT05	101.2	98.9	2.3	99.5	97.3	2.1	1.7	1.5	0.2
	IT06	96.0	99.0	-3.0	94.4	97.4	-3.0	1.6	1.6	0.1
Norway	NW01	88.4	99.0	-10.6	86.9	97.4	-10.5	1.5	1.6	-0.1
	NW02	99.0	98.9	0.1	97.4	97.4	0.0	1.7	1.6	0.1
	NW03	95.3	98.9	-3.6	93.7	97.4	-3.7	1.6	1.5	0.1
	NW04	95.0	98.9	-4.0	93.4	97.4	-4.0	1.6	1.6	0.0
Spain	SP01	105.1	98.8	6.3	103.4	97.3	6.1	1.8	1.6	0.2
	SP02	102.4	98.9	3.5	100.7	97.3	3.4	1.7	1.6	0.2
	SP03	90.3	98.8	-8.6	88.7	97.2	-8.5	1.5	1.6	0.0
	SP04	97.8	98.9	-1.1	96.2	97.4	-1.2	1.6	1.6	0.1
	SP05	96.0	98.6	-2.6	94.4	97.1	-2.7	1.6	1.6	0.0
	SP06	93.4	99.0	-5.5	91.9	97.4	-5.5	1.6	1.6	0.0
United Kingdom	UK01	102.7	98.9	3.8	101.0	97.3	3.7	1.7	1.6	0.2
	UK02	93.5	98.9	-5.4	92.0	97.4	-5.4	1.6	1.5	0.0
	UK03	91.4	99.0	-7.6	89.8	97.4	-7.5	1.5	1.6	0.0
	UK04	83.3	99.0	-15.8	81.9	97.5	-15.6	1.4	1.6	-0.2
	UK05	97.3	98.9	-1.7	95.6	97.4	-1.7	1.6	1.6	0.1
	UK06	93.1	98.9	-5.8	91.5	97.4	-5.8	1.5	1.5	0.0
Fuels	NGAS	84.8	98.8	-14.0	0.7	0.8	-0.1	84.1	98.0	-13.9
	OIL	100.3	98.9	1.4	0.8	0.7	0.1	99.4	98.2	1.2
Average spillover		98.9	98.9	0.0	95.7	95.7	0.0	3.2	3.2	0.0

Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPSS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. We use a classification of $q = 2$ groups or markets, defined as fuel (natural gas and oil) and energy stock markets. Source: Authors.

Appendix A6. Spillover decomposition between energy firms and fuel markets: 5th quantile.

Country	ID code	Total spillover index			Specific-market spillover (internal)			Cross-market spillover (external)		
		To other	From others	Net	To other	From others	Net	To other	From others	Net
Canada	CA01	90.5	99.2	-8.7	89.0	97.6	-8.5	1.5	1.7	-0.2
	CA02	98.6	99.1	-0.6	96.9	97.5	-0.6	1.6	1.6	0.0
	CA03	99.1	99.1	0.0	97.4	97.5	-0.1	1.7	1.7	0.0
	CA04	98.2	99.2	-0.9	96.6	97.5	-0.9	1.6	1.7	0.0
	CA05	98.5	99.1	-0.7	96.8	97.5	-0.7	1.6	1.7	0.0
	CA06	91.9	99.2	-7.3	90.4	97.6	-7.2	1.6	1.6	-0.1
	CA07	97.8	99.2	-1.4	96.1	97.5	-1.4	1.7	1.6	0.0
	CA08	97.3	99.2	-1.9	95.7	97.5	-1.8	1.6	1.7	0.0
	CA09	95.3	99.2	-3.9	93.7	97.5	-3.8	1.6	1.6	0.0
	CA10	93.4	99.2	-5.8	91.8	97.5	-5.7	1.6	1.6	0.0
	CA11	97.1	99.2	-2.0	95.5	97.5	-2.0	1.6	1.7	0.0
	CA12	93.1	99.2	-6.1	91.6	97.6	-6.0	1.5	1.6	-0.1
	CA13	99.7	99.1	0.5	98.0	97.5	0.5	1.7	1.7	0.0
	CA14	94.9	99.2	-4.2	93.3	97.6	-4.2	1.6	1.6	0.0
	CA15	97.7	99.2	-1.5	96.0	97.5	-1.5	1.7	1.7	0.0
	CA16	100.4	99.1	1.3	98.7	97.5	1.2	1.7	1.6	0.1
	CA17	100.2	99.1	1.1	98.6	97.5	1.1	1.7	1.7	0.0
	CA18	99.2	99.1	0.1	97.6	97.5	0.1	1.7	1.6	0.0
	CA19	94.8	99.2	-4.4	93.2	97.5	-4.3	1.6	1.6	-0.1
	CA20	95.9	99.2	-3.3	94.3	97.6	-3.3	1.6	1.6	0.0
	CA21	100.6	99.1	1.5	98.9	97.5	1.4	1.7	1.6	0.1
	CA22	98.2	99.1	-1.0	96.5	97.5	-1.0	1.7	1.6	0.0
	CA23	100.5	99.1	1.4	98.8	97.5	1.4	1.7	1.7	0.0
	CA24	97.2	99.2	-2.0	95.5	97.5	-2.0	1.6	1.7	0.0
	CA25	101.4	99.1	2.2	99.7	97.5	2.2	1.7	1.6	0.1
	CA26	97.4	99.2	-1.8	95.7	97.5	-1.8	1.6	1.7	0.0
	CA27	96.8	99.2	-2.3	95.2	97.5	-2.3	1.6	1.6	0.0
United States	US01	111.6	99.0	12.6	109.7	97.4	12.3	1.9	1.6	0.2
	US02	104.3	99.1	5.2	102.6	97.5	5.1	1.8	1.6	0.1
	US03	100.9	99.1	1.8	99.2	97.5	1.7	1.7	1.6	0.1
	US04	100.0	99.1	0.9	98.3	97.5	0.8	1.7	1.6	0.1
	US05	105.0	99.1	5.9	103.2	97.4	5.8	1.7	1.6	0.1
	US06	100.7	99.1	1.6	99.0	97.5	1.5	1.7	1.6	0.0
	US07	101.1	99.1	1.9	99.4	97.5	1.9	1.7	1.6	0.0
	US08	101.6	99.1	2.5	99.9	97.5	2.5	1.7	1.6	0.1
	US09	102.6	99.1	3.5	100.8	97.4	3.4	1.7	1.7	0.1
	US10	102.9	99.1	3.8	101.2	97.5	3.8	1.7	1.7	0.1
	US11	104.3	99.1	5.2	102.6	97.5	5.1	1.8	1.6	0.1
	US12	108.2	99.1	9.2	106.4	97.4	9.0	1.8	1.6	0.2
	US13	101.9	99.1	2.8	100.2	97.4	2.8	1.7	1.7	0.0
	US14	106.5	99.1	7.4	104.7	97.4	7.3	1.8	1.7	0.1
	US15	100.1	99.1	1.0	98.4	97.5	0.9	1.7	1.6	0.1
	US16	101.4	99.1	2.3	99.7	97.5	2.2	1.7	1.7	0.1
	US17	100.2	99.1	1.0	98.5	97.5	1.0	1.7	1.6	0.0
	US18	103.3	99.1	4.2	101.6	97.4	4.2	1.7	1.7	0.1
	US19	102.8	99.1	3.8	101.1	97.4	3.7	1.7	1.7	0.1
	US20	103.7	99.1	4.6	102.0	97.4	4.6	1.7	1.7	0.1
	US21	100.1	99.1	0.9	98.4	97.5	0.9	1.7	1.6	0.0
	US22	103.6	99.1	4.6	101.9	97.4	4.4	1.8	1.6	0.1
	US23	101.0	99.1	1.9	99.3	97.5	1.8	1.7	1.7	0.1
	US24	99.9	99.1	0.8	98.3	97.5	0.8	1.7	1.7	0.0
	US25	105.9	99.1	6.8	104.1	97.4	6.7	1.8	1.7	0.1
	US26	104.6	99.1	5.5	102.9	97.4	5.5	1.7	1.7	0.1
	US27	102.4	99.1	3.3	100.7	97.5	3.2	1.7	1.7	0.1
	US28	104.1	99.1	5.0	102.3	97.4	4.9	1.7	1.6	0.1
	US29	95.1	99.2	-4.1	93.5	97.5	-4.0	1.6	1.7	0.0
	US30	106.4	99.1	7.4	104.7	97.4	7.2	1.8	1.6	0.1
	US31	104.2	99.1	5.1	102.4	97.5	4.9	1.8	1.6	0.1
	US32	101.6	99.1	2.4	99.9	97.5	2.4	1.7	1.6	0.0
	US33	100.3	99.1	1.2	98.7	97.5	1.2	1.7	1.7	0.0
	US34	101.5	99.1	2.4	99.8	97.5	2.3	1.7	1.7	0.0
	US35	103.9	99.1	4.8	102.2	97.4	4.7	1.7	1.7	0.1

	US36	110.3	99.0	11.2	108.4	97.4	11.1	1.8	1.7	0.2
	US37	101.8	99.1	2.7	100.2	97.5	2.7	1.7	1.6	0.0
	US38	97.4	99.2	-1.8	95.8	97.5	-1.7	1.6	1.7	0.0
	US39	99.6	99.1	0.5	97.9	97.5	0.5	1.7	1.7	0.0
	US40	106.1	99.1	7.0	104.3	97.4	6.9	1.8	1.7	0.1
	US41	99.2	99.1	0.0	97.5	97.5	0.0	1.7	1.6	0.0
	US42	106.2	99.1	7.1	104.5	97.4	7.0	1.8	1.6	0.1
	US43	95.4	99.2	-3.8	93.8	97.5	-3.7	1.6	1.7	-0.1
China	CH01	91.6	99.2	-7.6	90.1	97.6	-7.5	1.5	1.7	-0.1
	CH02	98.2	99.2	-0.9	96.5	97.5	-1.0	1.7	1.6	0.0
	CH03	98.6	99.2	-0.6	96.9	97.5	-0.6	1.6	1.6	0.0
	CH04	98.8	99.1	-0.3	97.2	97.5	-0.3	1.7	1.7	0.0
	CH05	96.2	99.2	-2.9	94.6	97.5	-2.9	1.6	1.6	0.0
	CH06	90.0	99.2	-9.2	88.5	97.6	-9.1	1.5	1.7	-0.1
	CH07	92.8	99.2	-6.3	91.3	97.6	-6.3	1.6	1.6	-0.1
	CH08	93.8	99.2	-5.4	92.2	97.5	-5.3	1.6	1.6	-0.1
	CH09	96.8	99.2	-2.4	95.1	97.5	-2.4	1.6	1.6	0.0
	CH10	94.2	99.2	-5.0	92.6	97.5	-4.9	1.6	1.7	-0.1
	CH11	94.1	99.2	-5.1	92.5	97.5	-5.0	1.6	1.7	-0.1
	CH12	95.3	99.2	-3.9	93.7	97.5	-3.9	1.6	1.6	0.0
	CH13	93.5	99.2	-5.7	91.9	97.6	-5.7	1.6	1.6	-0.1
	CH14	94.8	99.2	-4.3	93.2	97.5	-4.3	1.6	1.6	-0.1
	CH15	98.4	99.2	-0.7	96.7	97.5	-0.8	1.7	1.6	0.1
	CH16	98.3	99.1	-0.8	96.7	97.5	-0.8	1.6	1.7	0.0
	CH17	97.3	99.2	-1.8	95.7	97.5	-1.8	1.6	1.6	0.0
Japan	JP01	92.1	99.2	-7.1	90.6	97.6	-6.9	1.5	1.7	-0.1
	JP02	97.3	99.2	-1.8	95.7	97.5	-1.8	1.6	1.6	0.0
	JP03	98.1	99.1	-1.0	96.5	97.5	-1.0	1.7	1.7	0.0
	JP04	92.8	99.2	-6.4	91.3	97.6	-6.3	1.6	1.6	-0.1
	JP05	96.3	99.2	-2.8	94.7	97.5	-2.8	1.6	1.6	0.0
	JP06	92.1	99.2	-7.2	90.5	97.6	-7.1	1.5	1.6	-0.1
France	FR01	97.2	99.1	-1.9	95.6	97.5	-1.9	1.6	1.6	0.0
Germany	GE01	99.6	99.1	0.5	98.0	97.5	0.5	1.7	1.6	0.0
	GE02	97.8	99.2	-1.4	96.1	97.5	-1.4	1.7	1.6	0.0
Italy	IT01	99.7	99.1	0.5	98.0	97.5	0.5	1.7	1.6	0.0
	IT02	102.7	99.1	3.6	101.0	97.5	3.5	1.7	1.7	0.1
	IT03	98.4	99.1	-0.8	96.7	97.5	-0.7	1.6	1.6	0.0
	IT04	98.6	99.1	-0.6	96.9	97.5	-0.6	1.7	1.7	0.0
	IT05	99.2	99.1	0.0	97.5	97.5	0.0	1.7	1.7	0.0
	IT06	97.7	99.2	-1.4	96.1	97.5	-1.4	1.6	1.7	0.0
Norway	NW01	95.5	99.2	-3.6	93.9	97.5	-3.6	1.6	1.7	-0.1
	NW02	96.3	99.2	-2.9	94.7	97.5	-2.8	1.6	1.6	0.0
	NW03	98.8	99.1	-0.4	97.1	97.5	-0.4	1.7	1.7	0.0
	NW04	96.6	99.2	-2.6	95.0	97.5	-2.5	1.6	1.7	-0.1
Spain	SP01	104.7	99.1	5.6	102.9	97.4	5.5	1.8	1.7	0.1
	SP02	99.2	99.1	0.1	97.5	97.5	0.0	1.7	1.6	0.0
	SP03	99.3	99.2	0.1	97.6	97.5	0.1	1.7	1.6	0.0
	SP04	93.8	99.2	-5.4	92.2	97.5	-5.3	1.6	1.7	-0.1
	SP05	98.1	99.2	-1.1	96.4	97.5	-1.1	1.7	1.7	0.0
	SP06	101.6	99.1	2.5	99.9	97.5	2.4	1.7	1.7	0.1
United Kingdom	UK01	100.5	99.1	1.4	98.8	97.5	1.3	1.7	1.6	0.1
	UK02	98.8	99.1	-0.3	97.1	97.5	-0.4	1.7	1.6	0.0
	UK03	101.3	99.1	2.2	99.6	97.5	2.1	1.7	1.7	0.1
	UK04	92.1	99.2	-7.1	90.6	97.6	-7.0	1.6	1.6	-0.1
	UK05	100.4	99.1	1.2	98.6	97.5	1.1	1.7	1.6	0.1
	UK06	101.6	99.1	2.5	99.9	97.5	2.4	1.7	1.6	0.1
Fuels	NGAS	93.2	99.2	-6.0	0.8	0.9	-0.1	92.4	98.3	-5.9
	OIL	103.0	99.1	3.9	0.9	0.8	0.1	102.1	98.3	3.8
Average spillover		99.1	99.1	0.0	95.9	95.9	0.0	3.3	3.3	0.0

Note: Spillovers were computed through QVAR(1). Spillover measures consider a KPSS 20-step-ahead forecast error variance decomposition and a 250-days rolling-window. We use a classification of $q = 2$ groups or markets, defined as fuel (natural gas and oil) and energy stock markets. Source: Authors.