Chapter 9
The Spillover Effect from Oil and Gas Prices: Evidence of Energy Shocks from Diebold and Yilmaz Index

Lucía Ibáñez-Luzón, Festus Victor Bekun, Andrew Adewale Alola, and Daniel Balsalobre-Lorente

Abstract The current study contributes to the current debate on the energy-growth literature spillovers between crude prices, oil prices, and natural gas liquid composite prices. To this end, the recent novel Diebold and Yilmaz (2012) spillover index is utilized for daily realized data from January 2009 to October 31, 2019. The Diebold and Yilmaz index is employed given its uniqueness to highlight the following directional spillovers, total spillovers, pairwise spillover, and net spillover for the outlined variables. Further empirical investigation to accounts for both secular and cyclical properties is examined within the sampled framework. The study empirical results show a total spillover effect of 13.80% such that the contribution of shock from others is highest for liquefied natural gas (NGLC) price (43.2). The contribution of shocks to Brent price (7.5) and WTI price (3.0) was also received from others. Interestingly, the Brent price is observed to contribute the highest shock to others (41.4) considering the global adoption of the Brent crude oil as against the WTI which also contributes a shock of 12.9 to others. Based on these findings, several policy prescriptions were presented in the concluding section.

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9.1 Introduction

The energy sector is been on a trajectory of paradigm shift in the recent decades ranging from environmental degradation challenges to energy security of supply concerns. Thus, new voices arise clamoring that a change in the current energy model is pertinent. This chapter will explore the evolution of oil and natural gas prices to review some of the macroeconomic fundamentals that have an effect on energy markets. To understand the current energy mix paradigm, it is necessary to look deeper into its most relevant components, which currently are oil and other liquids, coal and natural gas, all of which are fossil fuels. The first component is coal, consumption of which is expected to decrease. The reason behind this is that it is one of the most polluting fossil fuels, and after COP21 agreements, many countries committed to limit its use (Adedoyin et al. 2020)

On the other hand, oil and natural gas consumption is expected to continue rising, even though their exploration, production, and consumption processes are also polluting in nature. Natural gas is expected to grow at a higher rate than other fossil fuels, benefiting from being the less polluting fossil fuel and the substitute of renewable energy sources (RES) in cases of low RES production. Furthermore, natural gas production has increased due to the well-known shale gas revolution.[1]

Looking at the evolution of natural gas and oil prices in the last nine years, it is observed that prices have decreased (Fig. 9.1). This tendency is stronger in the case of natural gas.

There are differences in price-setting among regions. While gas prices in North America are set at liquid trading hubs (mainly at the Henry Hub), in Europe wholesale gas is sold mostly via long-term contracts (where prices are hub-based or oil-linked, and often both). In Asia and emerging countries, gas prices are usually linked to oil prices due to the inexistence of established liquid hubs, explaining the impact of oil volatility over gas prices.

Brent Crude is a major trading classification of sweet light crude oil that serves as a benchmark price used when purchasing oil worldwide. Brent crude is extracted from the North Sea and it is used to price two-thirds of the world traded oil. There has been a 6.8% decrease in the Brent reference price, which was 35.19 €/MWh on September 30, 2010, and has moved to 32.78 €/MWh on September 30, 2019.

Henry Hub is an important market clearing pricing point. It is used in delivery contracts for LNG on a global basis. Gas producers can rely on Henry Hub as a

[1]Shale gas refers to natural gas that is trapped within shale formations. The combination of horizontal drilling and hydraulic fracturing has allowed access to large volumes of shale gas that were previously uneconomical to produce, and it has rejuvenated the natural gas industry, especially in the USA. It offers liquefaction developers a competitive advantage due to its competitive prices. Thanks to cheaper unconventional gas, the US gas prices have become more competitive resulting in significant LNG exports and liquefaction capacity hikes.

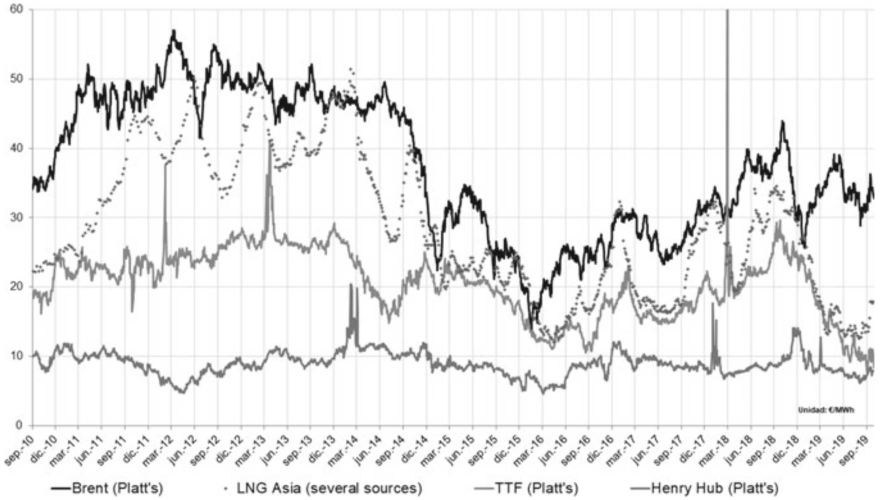

Fig. 9.1 Evolution of natural gas and oil prices (2010–2019). *Source* Own production based on Platts and other sources

source of natural gas spot pricing because of its large trading volume, clear pricing transparency, and high liquidity.

Henry Hub's price has decreased by 16.7% in the aforementioned period, mainly due to the increase in shale gas production. At present, shale gas represents close to 70% of the total US natural gas output and two-thirds of it are exported via pipeline to Mexico or as LNG globally.

Title Transfer Facility (known as TTF)is a virtual trading point for natural gas in the Netherlands. Located between the North Sea and Europe's main gas consumer, Germany, it allows gas to be traded within the Dutch Gas network. TTF products have been standardized to simplify their trading process. With prices relying on supply and demand dynamics, this natural gas hub is the largest European gas trading point, currently considered a benchmark at an EU level. There has been a 53.4% decrease in the day ahead price of TTF, which moved from 17.90€/MWh on September 30, 2010, to 8.35 €/MWh on September 30, 2019. Since the beginning of the year 2019, natural gas prices in Europe have plummeted due to a rising export war between Russia and the USA. According to Carlos Torres-Diaz, head of gas markets research at Rystad Energy, "The clear winners from the war between these two gas powers are the European end consumers, who benefit from record-low natural gas prices, and power prices which have dropped more than 30% in the last six months." Torres-Diaz also observed "As two of the world's largest gas producers, Russia, and the USA are natural competitors in what seems to be a race to the bottom, not only in the lucrative Asian market but now also in Europe. Both countries have sent increasing amounts of gas to Europe despite the low-price environment." Another reason behind this trend is the decrease in the consumption of natural gas and coal and the rise of electricity production with renewable energy sources.

Lastly, *LNG Asia*, it is the main natural gas hub in Asia and a global reference point for LNG trading. LNG Asia has seen a 19% decrease in the price of the index since September 2010. Spot LNG prices are at the lowest level they have been in years. "Asia's LNG prices have been in freefall since September 2018, as ample supply, sluggish demand and robust early stockpiling by China's SOEs (state-owned enterprises) largely capped prices over the winter months." Fitch Solutions reported "These factors, next to elevated growth headwinds and a forecast cooler summer, look set to keep a lid on prices over what should typically be a stronger season for gas demand." China and South Korea drove 85% of the growth for the period; LNG import level reflects a 29% increase from the previous year which can be attributed to "robust state-driven gasification efforts, to cut pollution and diversify away from coal," according to Fitch Solutions. Fitch Solutions notes that "a wave of new LNG supply additions" (many from North America) will "flood the Asia market."

With regard to the drop in oil prices, two differentiated trends have emerged; LNG prices are tending to converge and, a spread reduction between oil-linked and US market-based natural gas contracts. Supply and demand forces play the main role in the evolution of oil and gas prices. A deeper analysis of supply and demand dynamics is required to understand how these two markets are expected to evolve.

9.2 Energy Dynamics in Brief

The relationship between supply and demand determines the price of most goods and services; for this reason, a deep analysis of supply–demand forces is fundamental at this point to establish a connection between these market forces and price volatility in the energy sector. This subchapter goes through some macroeconomic fundamentals, necessary to understand forecasted demand movements. Demand for primary energy is ever-growing. Total energy consumption is expected to grow by 46% between 2018 and 2050. Among the principal reasons behind this are the increase in global population, GDP, and productivity.

The worldwide population has grown at a +11% rate between 2010 and 2018. At the moment, it accounts for 7.730 billion people, is expected to grow by 25%, reaching 9.650 billion people by 2050. Africa as a whole has grown by 25% since 2010 and is expected to grow by 84% between 2018 and 2050. China and India, which are the countries with greater absolute growth from 2010, are expected to keep growing at a high-speed rate, especially India (+21% up to 2050). A deceleration in Chinese growth is expected toward the end of the studied period as displayed in Fig. 9.2.

On the other hand, global energy demand is set to increase significantly driven by expansion in global output and increased prosperity in the developing world. Regarding global output, non-OECD-countries currently account for 56% of world-wide GDP and are expected to account for 86% of total GDP growth from 2018 to 2050. Non-OECD-countries are expected to grow by 226% in the following 32 years in comparison to OECD countries which growth is expected at 67%.

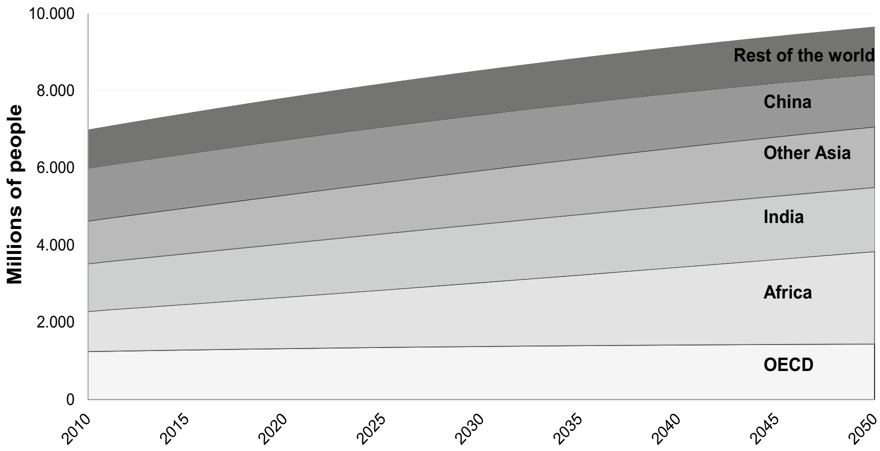

Fig. 9.2 Evolution of worldwide population (2010–2050). *Source* Own production based on EIA data

The country that is expected to grow at the greatest rate is India (+438%), followed by other Asian economies (+280%). Together Chinese and Indian GDPs are expected to account for around half of global GDP growth in 2050. On the contrary, Japan and Russia are expected to grow at the slowest rate, Japan at 9% and Russia 44%. The share of the African GDP in 2050 will account for 8% of global GDP while the weight of African population is expected to be 25%. On its yearly outlook, BP attributes this disparity to weak productivity.

Increases in per capita GDP account for 80% of the global expansion and lifts more than 2.5 billion people from low incomes, as pointed out by BP on its yearly outlook. The emergence of a large and growing middle class in the developing world is an increasingly important force shaping global economic and energy trends. GDP per capita is expected to grow at a rapid rate (up to 30% before 2050), with China (+69%) and India (+66%) displaying the highest rates of per capita GDP growth. The Chinese GDP per capita is expected to overpass Europe toward 2050. This rising prosperity and improvement in living standards supports increasing energy consumption per head (Fig. 9.3).

OECD and non-OECD countries are expected to follow different paths when it comes to energy demand since macroeconomic fundamentals are evolving differently. In 1990, OECD countries accounted for almost two-thirds of energy demand, with the developing world accounted just for one-third. In 2018, the OECD accounted for less than half of energy demand. In 2050, the situation is forecasted to be the reverse, with OECD countries accounting for one-third of global energy demand. At a time when the industrialization process is growing in some areas, Africa and Asia are on the way to achieving universal access to electricity by 2030. Since 2000, millions of new consumers have achieved access to electricity, and these figures will continue to rise rapidly.

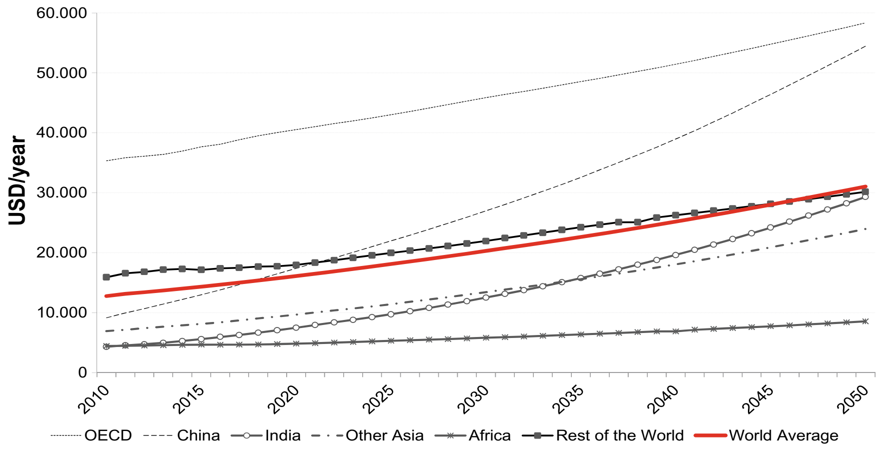

Fig. 9.3 Evolution of per capita GDP (2010–2050). Source Own production based on EIA data

Asia is expected to grow more in terms of primary energy demand in comparison to other regions. Currently representing 37% of global primary energy demand, it is expected to account for 43% of global energy demand by 2050. The Asian region accounted for nearly 40% of global energy demand in 2018 and this share has been rising rapidly. The main drivers if this growth are India and China; these two countries will continue growing at a rapid rate in the coming years. In 2018, India's energy demand accounted for onequarter of China's energy demand, whereas by 2050, the Indian demand is expected to account for half of the Chinese demand. This can be attributed to the efforts by the Chinese government to move towards an increasingly sustainable pattern of economic growth.

Africa's energy demand is expected to increase by 2%, a minimal increase in comparison with its expected population growth. Africa, by 2050, will be the home to one-quarter of the worldwide population; however, its energy demand will account for just 6% of the global primary energy demand. OECD countries are expected to reduce its energy consumption, due to a decrease in energy intensity in those countries.

Figure 9.4 presents primary energy demand distribution in 2018 and the forecasted one in 2050.

Coming back to oil and natural gas markets, both fossil fuels will continue playing an important role in the future. Natural gas consumption is expected to rise all over the world, without exception. This is especially true for China. In 2013, the Chinese government introduced the Air Pollution and Control Program, and ever since natural gas has played a fundamental role as the preferred alternative to coal. According to the International Energy Agency, in the next five years, China will become the world's leading importer of natural gas. China is expected to account for 37% of the global increase in natural gas consumption between 2017 and 2023, more than any other

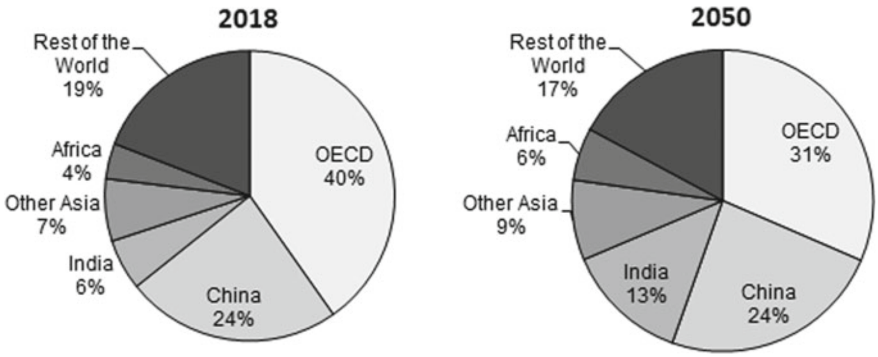

Fig. 9.4 Primary energy demand distribution. *Source* Own production based on EIA data

country. China's gas consumption is expected to move from being half that of the EU at the moment to 75% higher by 2040 (Fig. 9.5).

Regarding liquid fuels, its consumption is expected to show the greatest increase in India and greatest decrease in the OECD countries, due to environmental policies claiming for cleaner energy sources. India is estimated to display the biggest oil consumption growth between 2018 and 2050. Despite its efforts to reduce CO_2 emissions and increase usage of sustainable energy sources, the country will need to fill the demand gap with oil to cope with its expanding demand needs (Fig. 9.6).

On the supply side, the global pattern of energy production is also shifting, with strong growth in US energy production and a slowing in the expansion of Chinese

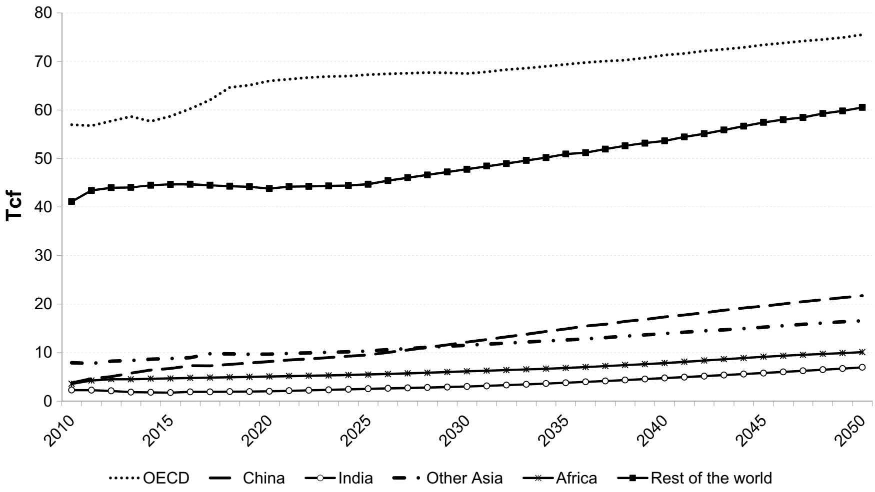

Fig. 9.5 Natural gas consumption evolution (2010–2050). *Source* Own production based on EIA data

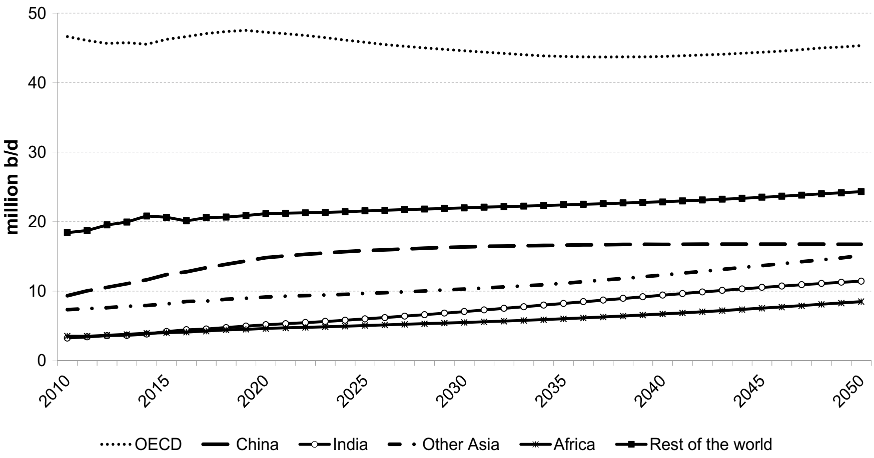

Fig. 9.6 Liquids consumption evolution (2010–2050). *Source* Own production based on EIA data

energy supplies. The US growth is related to the increase of shale oil and gas production from the Permian region. China, on the contrary, slows down due to an adjustment toward a more sustainable pattern of economic growth. The Middle East remains an elemental source of energy while Russian production is expected to slow down, even though it continues being the main oil and gas exporter.

Natural gas and oil will continue being key for growth. Oil will continue to be the most consumed energy source, while gas will be the fastest-growing fossil fuel, both fundamental components of the future energy mix.

9.2.1 *Energy-Related Crises*

Energy is essential for growth because it is a necessary input for every sector and a productivity driver. The linkage between economics and energy lead to energy security concerns at governmental levels.

Energy consumption affects various aspects of economic activity, having influence over long-run GDP growth and improvements in quality of life simultaneously. The reason for this is that energy is required in all industrial processes; therefore when there are energy shortages producing price spikes, they have a negative multiplicative effect over industrial costs. Then, higher industrial costs are translated into higher retail prices, leading to consumption crises. Higher energy prices lead to both a reduction in aggregate demand and a shift in expenditures which in turn cause a ripple effect throughout the economy, as firms adjust their production plans.

Some of the most relevant economic crises have been directly connected to energy crises. As good examples of this, the energy crises that took place in 1974 and 1981 proved the existence of nexus between energy consumption and economic growth since the late 1970s. Several economists (e.g., Kraft and Kraft 1978; Erol and Yu 1987; Soytas and Sari 2003; Alola 2019; Alola et al. 2019) explored the relationship between short- and long-run energy consumption and growth. The biggest threats leading to likely future energy crises currently are energy security of supply and climate change.

9.2.2 Energy Security of Supply and Market Concentration

Energy is scarce, which means that in the majority of the countries, internal production is not enough to meet demand needs (especially in countries that rely primarily on fossil fuels for energy production). On the other hand, a few countries have control over worldwide oil and gas production, often located in politically unstable areas. Concerns regarding the security of supply arise because there is a high reliance on energy (mainly fossil fuels) producers, and fossil fuel production is concentrated in a few countries.

One of the most recent energy crises where security of supply was compromised was the EU- Ukrainian crisis that brought focus on EU dependence on Russian gas. Russia currently accounts for as much as 34% of EU gas imports (2015), and for many new member states in Eastern Europe, the share is much higher. Supply disruptions derived from the crisis proved the importance for non-producing countries to have a diversified supply source portfolio. Security of supply is not just related to disruptions but also price volatility. According to the International Energy Agency, *security of supply means access to adequate supply of energy at a reasonable cost, proper investment in infrastructure and proper functioning of the system.*

Oil and gas reserves[2] are highly concentrated in a few hands. In 2018, 66% of natural reserves and 84% of crude oil reserves were held by ten countries. Natural gas CR3 is 44% while oil CR3 is 42%, meaning that three countries have power over more than 40% of global proven reserves in each market. Venezuela possesses the largest crude oil reserves (302.25 Billion Btu), followed by Saudi Arabia (170 Billion Btu), Canada (170.5 Billion Btu), and Iran (157.2 Btu). In the case of natural gas, Russia possesses the largest proven natural gas reserves (1688.33 Tcf), followed by Iran (1190.83 Tcf) and Qatar (850.1 Tcf) (Fig. 9.7).

On the other hand, most oil and gas producers are state-owned monopolies. In Russia, more than 50% of oil and gas production is owned by the Russian Federation state. There are other oil and gas state-owned monopolies such as BBOC in Nigeria or SONATRACH in Algeria, which are 100% owned by their governments not allowing private investments.

Ten countries own more than 60% of natural gas reserves and more than 80% of crude oil reserves, thus having direct influence over the rest of the countries

[2]Energy reserves are estimated quantities of energy sources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions.

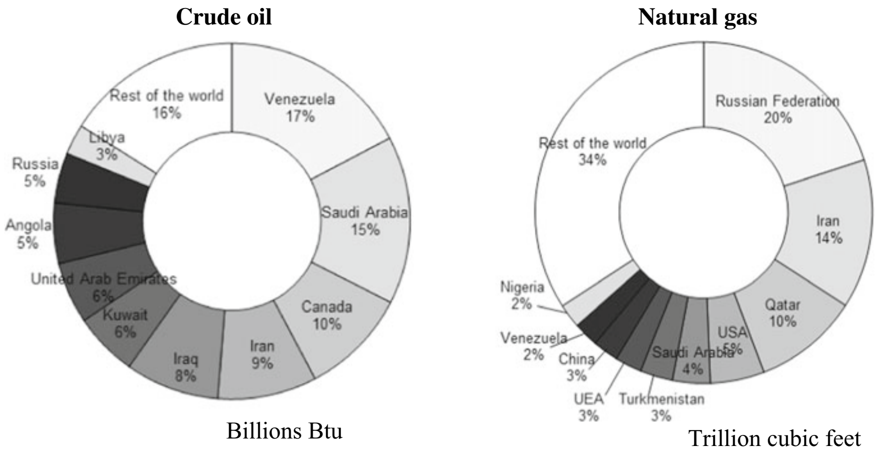

Fig. 9.7 Oil and gas proven reserves (2018). *Source* Own production based on EIA data

relying on them to satisfy their internal demand needs. The long-term implications of being dependent on monopolist, single-supply routes, and oil or natural gas as dominant energy forms can be detrimental to a country's welfare and independent policymaking.

9.2.3 Global Climate Crisis

The world is currently facing a global climate crisis. There has been an increase of 2 degrees Fahrenheit during the twentieth century ratified by the NASA which has led to global environmental change, "Effects that scientists had predicted in the past would result from global climate change are now occurring: loss of sea ice, accelerated sea-level rise and longer, more intense heat waves". The Intergovernmental Panel on Climate Change (IPCC) states that *"the range of published evidence indicates that the net damage costs of climate change are likely to be significant and to increase over time"*. In response to climate change, the United Nations Conference on Climate Change (COP21) in Paris in 2015 resulted in 195 countries approving the first universal, legally binding global climate deal on greenhouse gas emissions, known as the Paris Agreement. The Paris Agreement aims to keep the increase in global average temperature to well below 2 °C above pre-industrial levels and has been ratified by 187 countries till date and representing over 87.75% of emissions. Scientists have high confidence that global temperatures will continue to rise for decades to come, largely due to greenhouse gases produced by human activities. The world currently emits 35 billion tonnes of energy-related CO_2 each year. The IEA has calculated that energy-related CO_2 emissions need to fall to around 18 billion tonnes a year by 2040 to limit the rise in global temperature to 2 °C.

Fossil fuels produce large quantities of carbon dioxide when burned. Carbon emissions trap heat in the atmosphere and lead to climate change. The Intergovernmental Panel on Energy Studies' paper "Global warming of 1.5 °C" describes the impacts of global warming of 1.5 °C above pre-industrial levels and emphasizes the negative role played by fossil fuels and their contribution to global net CO_2 emissions. Looking at individual performances, India is expected to show the greatest increase in its CO_2 emission levels with a 161% jump in emissions from 2018 to 2050, followed by Africa with an increase of 96%. On the contrary, Japan is expected to improve the most, decreasing its emissions by 21% from 2018 to 2050, followed by the European Union, expected to reduce its emissions by 12% by 2050.

The EU has put in place legislation to reduce emissions by at least 40% by 2030—as part of the EU's 2030 climate and energy framework and contribution to the Paris Agreement. This includes revising the EU emissions trading system (EU ETS) national emissions targets for sectors outside the EU ETS. Japan, which is the world's fifth-biggest carbon emitter, is committed to reducing its greenhouse gas emissions by 80% by 2050. China is planning on implementing the ETS project. Figure 9.8 displays the forecasted evolution of CO_2 emissions by region.

Energy crises have a multiplicative effect over the economy since all industrial processes rely upon the energy factor and have proven that countries should rely upon more than just a few suppliers to cope with their demand needs to mitigate disruption risks and dependency issues. The reliance on polluting fossil fuels needs to be reduced to fulfill Paris Agreement requirements on the one hand and to reduce dependency on external producers on the other.

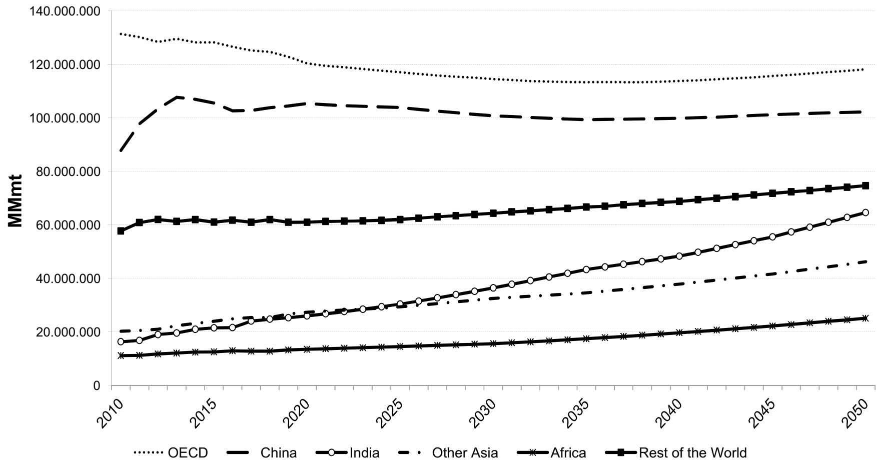

Fig. 9.8 Evolution of CO_2 emissions (2010–2050). *Source* Own production based on EIA data

9.2.4 Green Energy

At present, when energy security of supply is fundamental and climate change is at a crucial stage, it is of great importance to rethink how to deal with forecasted increasing demand a more sustainable manner. As strategies to secure energy supply while facing environmental challenges, there are two best-practice options, one from the supply side and the other from the demand side. From the supply side, it relates to renewable energy sources and from the demand side to energy efficiency and conservation.

9.2.5 Energy Efficiency and Conservation

Energy efficiency implies a reduction in the amount of energy consumed per produced unit of output. Energy intensity is a measure of the energy efficiency of an economy. It is calculated as units of energy per unit of GDP; low energy intensity indicates a lower price or cost of converting energy into GDP. Therefore, energy intensity and energy efficiency demonstrate an inverse relationship, with a decrease in energy intensity, resulting in an increase in the energy efficiency. To comply with United Nations Sustainable Development Goal 7 (SDG 7), energy intensity needs to undergo huge reductions. For this, many countries have issued national policies regarding energy efficiency and energy intensity. At a European level, Directive 2012/27/EU on energy efficiency establishes a common framework of measures for the promotion of energy efficiency within the European Union to achieve the headline target of a 20% reduction in primary energy consumption by 2020 (EC reference).

Worldwide energy intensity is expected to be reduced by 42% before 2050, taking as a base case 2018 scenario as presented in Fig. 9.9.

China is expected to improve the most in energy efficiency terms, reducing its energy intensity by 57% from 2018 to 2050. China has already started developing its economy toward the achievement of an energy intensity reduction, achieving a 24% improvement from 2010 to 2018. Other Asian countries are expected to improve by 46%, followed by Africa which will improve by 39%. Improvements in energy efficiency simultaneously address energy security, affordability, and environmental concerns, contributing to CO_2 reduction. Measures could be taken at a household and non-household level. At a household level, efficiency plays a major role in transport, house cooling, cooking systems, among others. In transport, road passenger vehicles should use almost 50% less fuel per kilometer traveled in 2040 compared with today to comply with environmental agreements, supported by strengthened fuel economy standards and larger uptake of electric vehicles, avoiding 20 Mtoe of fuel consumption in road transport. In the infrastructure sector, energy efficiency measures bring additional savings. This reflects more stringent Minimum Efficiency Performance Standards for appliances and particularly for cooling equipment. To

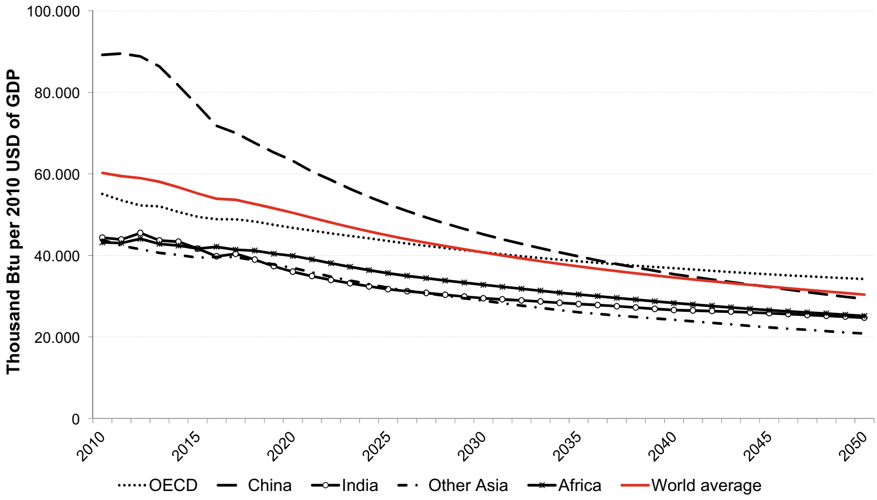

Fig. 9.9 Energy intensity evolution (2010–2050). *Source* Own production based on EIA data

comply with Paris agreement requirements by 2040, the industrial sector's average energy intensity may decrease by 50% from present levels, largely due to increases in recycling rates and equipment efficiency.

9.2.6 Clean Energy Sources

Despite the importance of energy efficiency measures, these will not be enough to cope with increasing energy demand needs. To grow more sustainably, cleaner energy sources need to grow in detriment of pollutant energy sources. Figure 9.10 presents Pounds CO_2 per MBtu per fossil fuel, showing the importance of eliminating coal and other pollutant fuels in the process of energy production. All types of coal and fuels are highly pollutant, as per Fig. 9.10. Natural gas produces the lowest dioxide emissions among fossil fuels, due to which it may emerge as an essential transition fuel to combat global climate change, along with renewable energies.

Out of all energy sources, renewables have proved to be the cleanest, safest, and most reliable for electricity production. Electricity production from RES is possible at low or even zero carbon emission levels, because of which they are gaining importance relative to oil and coal. Further, RES are attractive for the supply chain due to their benefits; moving away from fossils fuels removes the risk of price fluctuations and regulatory changes, they also attract customers interested in corporate and environmental responsibility. Nowadays, RES are also more affordable and accessible than ever, as the cost per kWh of the energy they produce continues to fall.

Solar energy and wind energy are the world's biggest sources of renewable energy and grow in popularity each year. Other notable sources of energy for the future

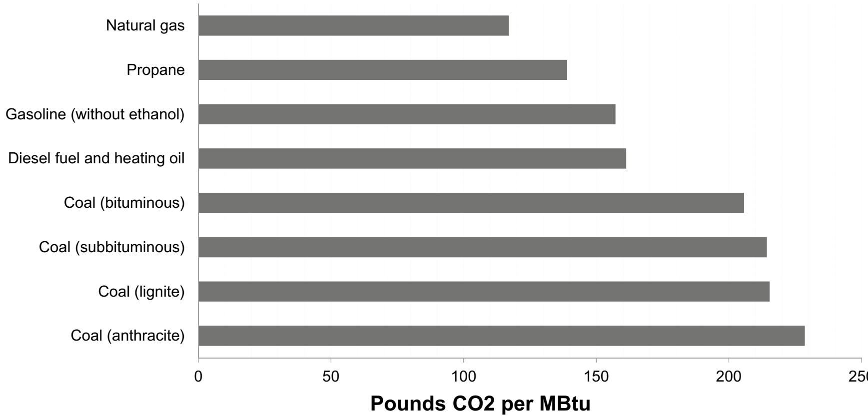

Fig. 9.10 Carbon dioxide emissions coefficients by fuel. *Source* Own construction based on EIA data

are nuclear power and geothermal energy. Nuclear power has its share of concerns; however, as technology develops, it may become a viable replacement for centralized fossil fuel power stations. Geothermal energy is another option, although it is more limited.

Many countries are adopting RES for electricity production. One of them is Iceland, the country generated the cleanest electricity per capita in the world, with almost 100% of RES production, and its generation mix is based on geothermal and hydroelectric power plants. Another example is Costa Rica, Costa Rica can meet a large part of its energy needs from hydroelectric, geothermal, solar, and wind sources, and it is committed to be completely carbon neutral by 2021. In Uruguay, owing to a supportive regulatory environment and a strong partnership between the public and private sectors, the country has invested heavily in wind and solar power, without using subsidies or increasing consumer costs. Thus, as an outcome of Uruguay's efforts, in less than ten years, 95% of its electricity production comes from renewables.

At a global level, the total installed capacity of renewable energy sources is expected to quadruple in following 30 years, from 2,340 quads Btu in 2018 to reach approximately 8,126 quads Btu by 2050. The growth in renewable energy is dominated by the developing world, with China, India, and other Asian countries accounting for nearly half of the growth in global renewable power generation, as noted by BP in their yearly Outlook. For example, in India, total RES installed capacity is expected to increase over tenfold, from 112 quads Btu in 2018 to 1478 quads Btu in 2050. In 2018, OECD countries account for 44% of total RES installed capacity, followed by China (30% of global share). By 2050, China is expected to have the biggest installed capacity share (34%), followed by OECD countries (33%). At present, China is the world's largest polluter; however, it is also the biggest investor in renewable energy in the world, incentivizing its cities to reduce fossil fuel consumption and heavily investing in RES (Fig. 9.11).

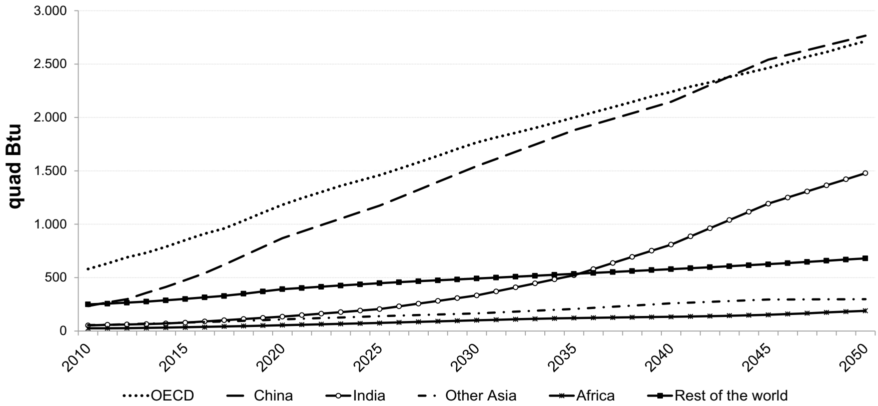

Fig. 9.11 RES installed capacity (2010–2050). *Source* Own construction based on EIA data

While discussing clean energy sources and the many advantages they offer, it also important to mention some of the concerns that require attention. The primary issue with renewable energies is that they rely on weather conditions; hence, they face intermittency problems, alternating periods of high production with periods of low production.

Cost-efficient energy storage systems are fundamental to ensuring that excess energy generated in peak periods can be used to shore up the gaps when generation is lower. Along with storage systems, well-interconnected systems help to tackle intermittency problems in a more efficient way. At the European Union level, a strong and fast-growing interconnection of the grid on an EU level has been already achieved as a tool to deal with national consumption peaks.

Despite the existence of storage facilities and efficiently interconnected markets in some areas, there is still a demand gap to be hedged via other energy sources. Natural gas is viewed as a complementary energy source for wind and solar energies, enabling its greater adoption.

RES and natural gas will be fundamental energy sources in the future, although oil will also continue playing a central role. Figure 9.12 displays the evolution of the future worldwide energy mix. Between 2018 and 2040, renewable energy is the fastest-growing source of energy, contributing half of the growth in global energy supplies and becoming the largest source of power by 2040. Renewable energies are expected to grow by (+64%) from 2018, followed by natural gas (+40%) and nuclear energy (+36%). The demand for liquid fuels grows for the first part of the period before gradually plateauing. On the contrary, coal's share is forecasted to decrease by 0.2% mainly due to the general aim to reduce CO_2 emissions. The largest source of energy will continue being liquids. Natural gas grows more rapidly than both oil and coal, overtaking coal to be the second-largest source of global energy. Coal consumption will decline to its lowest level since before the industrial revolution. The fall in coal consumption can be attributed Chinese policies against the usage of

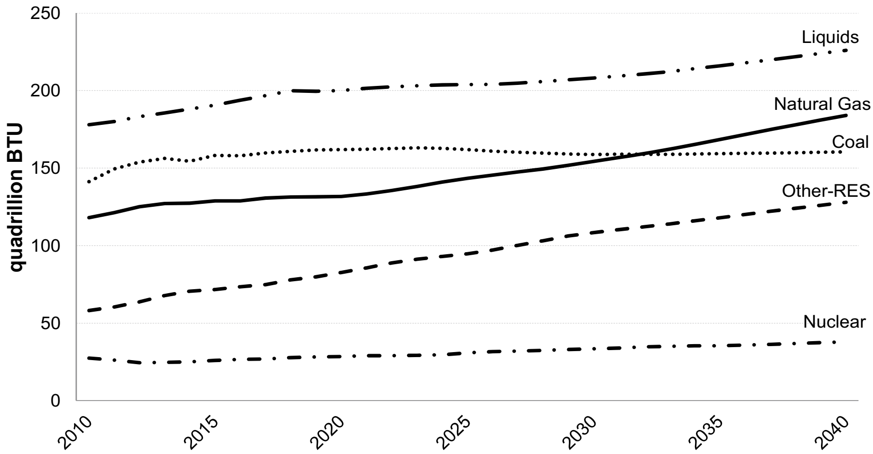

Fig. 9.12 World energy consumption by energy source (2010–2040). *Source* Own construction based on EIA data

coal, partly balanced with consumption increases in other Asian countries, such as India.

Cleaner energy sources, natural gas, nuclear, and renewable energies will account for 47% of total energy demand in 2040, while they account for 39% presently. Taking a look at liquids, they currently account for 33% of the total energy consumption, a trend that is expected to change, accounting for just 13% in 2040 as displayed.

The rest of this study is structured as: Sect. 9.2 provides a brief of the related literature while data and method are offered in Sect. 9.3. Section 9.3.2 presents the empirical discussion. Finally, Sect. 9.4 provides the concluding remark.

9.3 Methodological Procedure

9.3.1 Data Source

The present study relies on the Diebold and Yilmaz (DY, hereafter) to evaluate the interconnectedness between the variables: crude oil (Brent), world Texas intermediate (WTI) oil prices, liquefied natural gas prices and Henry Hub (Platt's) prices for daily realized data from January 1, 2009 to October 31, 2019. The data were sources from the Federal Reserve Bank of St. Louis (FRED) database (https://fred.stlouisfed.org/). In Table 9.1, further description of the data series containing the unit representation and code is presented.

In addition, the descriptive statistics and the correlation matrix of the employed data are presented in Table 9.2. From the information in Table 9.2, it is observed that the Brent crude oil (Brent) price exhibits the highest volatility considering the

Table 9.1 Indicators and unit of measurement

Variables	Code unit of measurement	Source
Brent crude oil	Brent price US dollars	FRED
World texas intermediate	WTI price US dollars	FRED
Liquefied natural gas prices	NGLC price US dollars	FRED
Henry hub (Platt's)	HH price US dollars	FRED

Source Authors' compilation
Note The data from Fred Louis database is available in https://fred.stlouisfed.org/

Table 9.2 The descriptive statistics

Variables	WTI price	Brent price	HH price	NGLC price
Mean	71.7256	78.3126	3.379721	8.871054
Median	70.645	74.43773	3.23	9.06
Maximum	113.39	124.9286	8.15	15.88
Minimum	26.19	30.80333	1.49	3.69
Std. Dev.	21.61529	25.68288	0.882746	3.200221
Skewness	0.065804	0.177234	0.742494	0.415471
Kurtosis	1.694211	1.652177	4.188278	2.334166
Jarque-Bera	195.4932*	220.4482*	410.5516*	128.686*
Correlation matrix				
	WTI price	Brent price	HH price	NGLC price
WTI price	1			
Brent price	0.969753*	1		
	(207.2814)	–		
HH price	0.462443*	0.386749*	1	
	(27.21139)	(21.88037)	–	
NGLC price	0.817689*	0.814634*	0.551916*	1
	(74.10807)	(73.28196)	(34.53055)	–

Note The WTI, BRENT, HH, and NGLC are, respectively, the West Texas Intermediate crude oil prices, Brent crude oil prices, Henry Hub natural gas spot price, and US Natural Gas Liquid Composite price. Also, the * is the statistical significant level at 1% and () is the test statistic

maximum and minimum values as well as the standard deviation. This is illustratively followed by the World Texas Intermediate (WTI) price, the liquefied natural gas (NGLC) price, and the Henry Hub (Platt's) prices. Similarly, the evidence of correlation among the each pair of the variables is statistically significant as evidently shown in Table 9.2. However, the correlation evidence between WTI and Brent crude oil prices, NGLC and Brent prices, and Brent crude oil and NGLC prices is all statistically significant especially with a correlation coefficient of more than 0.80.

Table 9.3 Spillover Index

Variables	WTI price	Brent price	HH price	NGLC price	From others
WTI price	**97**	3	0	0	3
Brent price	7.5	**92.5**	0	0	7.5
HH price	1.1	0	**98.7**	0.2	1.3
NGLC price	4.4	38.4	0.4	**56.8**	43.2
Contribution to others	12.9	41.4	0.5	0.2	**55**
Contribution including own	110	133.9	99.2	57	13.80%

Note The WTI, BRENT, HH, and NGLC are, respectively, the West Texas Intermediate crude oil prices, Brent crude oil prices, Henry Hub natural gas spot price, and US Natural Gas Liquid Composite price

9.3.2 Empirical Method

This study applies DY to evaluate the interconnectedness between the outlined variables under review. In the application of the DY approach, the order of selection of the variables is not important just as the techniques do not significantly suffer from other econometric problems such as the serial correlation and heteroskedasticity. The DY techniques are novel on the premise of its less rigorous computational requirements that aid the characterization that reflects diverse events and episodes. The DY procedure is built on the vector autoregressive (VAR) and variance decomposition setting. Diebold and Yilmaz (2009) is structured in the VAR framework that is sensitive to the order orientation of the variables after the Cholesky factorization. However, the extended version of the Diebold and Yilmaz (2012) ameliorate for the shortcomings of the 2009 version that does not take into account the order orientation (Koop et al. 1996; Pesaran and Shin 1998).

The Diebold–Yilmaz index highlights four spillovers indices, namely directional spillovers pairwise spillover, net spillover, and total spillovers. The DY setup is based on a covariance stationary VAR:

$$y_t = \Phi_0 + \sum_{i=1}^{n} \Phi_i y_{t-i} + \varepsilon_t$$

Here, $y_t = (y_{1t}, y_{2t}, \ldots, y_{nt})'$ is a vector of covariance stationary series Φ_i, $i = 0, 1, 2, \ldots, p$, denotes $(n \times n)$ matrix of parameters ε_t is a $(n \times 1)$ vector of zero mean errors required to be independent and identically (*iid*) distributed with covariance matrix Σ, $\varepsilon_t \sim iid(0, \Sigma)$.[3]

However, the estimates of the DY result are presented in Table 9.3 in addition with the spillover rolling window in Fig. 9.1. Accordingly, the pairwise result indicates

[3]For the want of space, interested reader on the DY indices see the Studies of Diebold and Yilmaz (2009, 2012, 2014).

that the spillover effect from Brent price to NGLC price is the highest (38.4), thus indicating that there is higher possibility for the contagion of shock (resulting from volatility and other forms of uncertainty) from the event surrounding the dynamics of Brent crude oil price to the liquefied natural gas price. This evidence was earlier investigated in the study of Panagiotidis and Rutledge (2007) that found a significant evidence of cointegration between the United Kingdom (UK) gas and the oil prices. Similarly, the study of Geng et al. (2016) found a significant evidence of multi-scale impact of oil price shock on gas markets especially in the pre- and post-revolution. While the study also found a significant linkage between oil price and shale gas revolution, the effect of oil price on Henry Hub price is found to be significant but weaker. Similarly, the spillover effect caused by shock in the World Texas Intermediate (WTI) price to the Brent price, NGLC price, and HH price are respectively 7.5, 4.4, and 1.1.

Furthermore, the impact of the contribution to and from others is observed to yield a significant total spillover effect of 13.80% as illustrated in Table 9.3. The spillover effect (caused by shock) from the combined series is observed to be higher in the order of NGLC (43.2), Brent price (7.5), the WTI price (3), and HH price (1.3). The implication is that the liquefied natural gas is more impact whenever there is shock among the estimated markets of oil and gas prices. Similarly, the spillover effect contribution from Brent price to other estimated market commodities is highest (41.4) and followed by the spillover effect from the WTI price to other market commodities (12.9). Intuitively, it is not a surprise that the contribution from Brent price to other market commodities is highest considering the significant of Brent crude oil globally. The reason is because the Brent and WTI are the two dominant oil reference prices globally while the Brent crude oil most preferred because it relative advantages (Álvarez-Díaz 2019; Caporin et al. 2019; Caro et al. 2020) (Fig. 9.13).

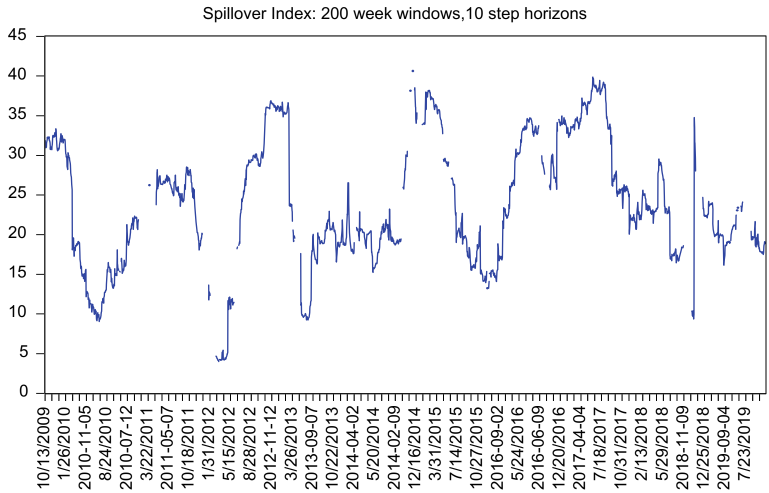

Fig. 9.13 The spillover rolling window

9.4 Concluding Remark and Policy Direction

In all oil and natural gas markets, supply and demand forces play the main role in price formation despite price-setting differences. Demand for primary energy is ever-growing, with the developing world increasing its role as the main consumer. Total energy consumption is expected to grow by 46% between 2018 and 2050 driven by an increase in worldwide population and purchasing power from developing countries (headed by China and India). At the same time, the world is currently facing a climate crisis. Fossil fuels are the most polluting energy sources and their production is located in only a few countries, leading to dependency risk. Hence, it is necessary to rethink how to deal with forecasted increasing demand in a more sustainable way.

As strategies to secure energy supply while facing the environmental challenge, the two best options are the promotion of energy efficiency and greater investments in renewable energy domestic production. On the one hand, global energy efficiency is expected to improve by 42% between 2018 and 2050. While on the other hand, renewable installed capacity is expected to increase in all areas. Renewable energy sources are expected to be the fastest-growing energy source followed by natural gas which will help RES to cope with intermittency issues.

To understand the current energy mix paradigm, it is necessary to look deeper into the most relevant components, which currently are oil (and other liquids), coal and natural gas, all of which are fossil fuels. Thus, the present study seeks to investigate the nature of interconnectedness between a cocktail of energy prices, natural gas, and crude oil prices. The investigation is conducted with the novel and recent methodology advanced by Diebold and Yilmaz (2012); the DY approach is robust and provides both secular and cyclical movement that distinct from previous volatility estimators. Empirical findings were based on daily realized data from January 2009 to October 31, 2019, to validate the hypothesized argument. Accordingly, the current examination from a total spillover effect of 13.80% such that the contribution of shock from others is highest for liquefied natural gas (NGLC) price (43.2). The contribution of shocks to Brent price (7.5) and WTI price (3.0) was also received from others. Interestingly, the Brent price is observed to contribute the highest shock to others (41.4) considering the global adoption of the Brent crude oil as against the WTI which also contributes a shock of 12.9 to others.

This study is not without policy directives and recommendation. Considering the importance of both the Brent crude oil (Brent) and the world Texas intermediate (WTI) in the global commodity markets, a more diversification of the global markets is essential. In adopting more economic diversification, the impact of oil shocks on other commodity markets, thus minimizing or avoiding any potential economic and financial crisis. During the implementation of similar study in the future, additional commodities that capture other commodities and financial markets could be incorporated in the study.

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