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Impact of Solar and Wind Prices on the Integrated Global Electricity Spot and Options Markets: A Time Series Analysis

Yasir Alsaedi[1, 2]*, Gurudeo Anand Tularam[2], and Victor Wong[3]

[1]Department of Mathematics, Umm Al-Qura University, Makkah, Saudi Arabia, [2]Environmental Futures Research Institute and School of Environment and Science, Griffith University, Australia, [3]Department of Accounting, Finance and Economics, Griffith University, Australia. *Email: yasir.alsaedi@griffithuni.edu.au

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ABSTRACT

Following the liberalisation of the global electricity markets, spot and options markets have been established in many countries. Electricity pricing issues, coupled with increased concern regarding global warming and the greenhouse effect, represent the driving factors behind electricity price movements. Australia, Germany, the United States (US) and other countries worldwide have increasingly shifted their focus away from fossil fuels and towards energy generated from renewable sources, including solar and wind power. This paper examines the behaviour of the Australian, German and US electricity markets in terms of the impact of solar and wind pricing on the electricity spot and options markets for the period January 2006 to March 2018. Using a vector autoregression analysis, we examine both the direction of influence and the influence absorption through Granger causality testing, the impulse response function and forecast error variance decompositions. Our findings indicate that the electricity markets in Australia, Germany and the US are interdependent and related with regards to solar and wind price changes, meaning that the investigated electricity markets are influenced by movements in other electricity markets. The findings of this study are important for investors, energy analysts, government organisations and policymakers.

Keywords: Electricity Pricing, Renewable Energy, VAR Model
JEL Classifications: C32, Q41, Q42

1. INTRODUCTION

The global electricity markets have undergone a radical transformation over the last two decades (Astier and Lambin, 2019; Benth and Schmeck, 2014; Sioshansi, 2013; Weron, 2014). During the mid-1990s, the electricity markets in most countries were characterized by monopoly pricing. However, during the last two decades, the electricity markets have been liberalised in Europe, the United States (US), Australia and other places worldwide (Astier and Lambin, 2019; Chen, 2019; Newbery, 2018). Typically, the markets can be classified as either day-ahead spot markets for electricity or financial contracts for the future delivery of power. In some more developed markets, one can also trade in derivatives, such as plain vanilla call, or even create exotic options for future contracts. Such possibilities currently exist in the NASDAQ OMX Commodities Europe (formerly Nord Pool) (Nikkinen and Rothovius, 2019), the German European Electricity Exchange (EEX) (Chen et al., 2019), the US PJM Electricity Option (Kang et al., 2019) and the Australian Securities Exchange Ltd (ASX) (Alsaedi et al., 2019; Maryniak et al., 2019) markets.

Alongside liberalisation efforts, concerns regarding environmental security, sustainability and climate change have grown in recent decades, forcing governments to find viable alternatives to the traditional energy sector so as to limit the negative impact on the environment. As a result, many countries have shifted their focus away from fossil fuels and towards energy generated from renewable sources, including solar and wind power (Bansal et al., 2019; Simshauser and Tiernan, 2019). To ensure the transition from fossil-fuel-based power generation to power generation via renewable sources, the United Nations introduced the Kyoto Protocol in 1997 (United Nations, 1998). It was intended to decrease states' greenhouse gas (GHG) emissions by at least 18%, when compared to their emissions in 1990, by 2020 (United Nations, 1998). Following the introduction of the Kyoto Protocol, the share of wind turbines (WT) and solar photovoltaic cells (PV) in the electricity generation mix has been rapidly increasing in a number of countries. Table 1 presents the growth in PV- and WT-based generation over the last 10 years in Australia, Germany and the US.

Table 1 shows that solar energy generation increased from 20 GWh in 2008 to 10,050 GWh in 2018 in Australia, from 4420 GWh in 2008 to 45,750 GWh in 2018 in Germany and from 76 GWh in 2008 to 63,012 GWh in 2018 in the US (Energy charts, 2019; Energy Information Administration (EIA), 2019; OpenNEM, 2019). Moreover, wind power generation increased at an average annual rate of 46.18%, 11.36% and 17.72% in Australia, Germany and the US, respectively, over the last decade (Energy charts, 2019; EIA, 2019; OpenNEM, 2019). This significant growth in both solar and wind energy generation has been driven by a number of factors, including the impressive improvements made in wind turbine technology and solar photovoltaic systems, growing environmental concerns (especially in relation to climate change) and the desire for less dependency on non-renewable energy sources (Zahedi, 2010).

The renewable energy sector is currently one of the fastest growing components of the global energy industry and, along with the increasing demand for renewable energy, there has been an increase in investment and financial activities in this regard. Figure 1 shows that the global investment in clean energy totalled $332.1 billion in 2018 (Bloomberg New Energy Finance [BNEF], 2019). Europe saw its clean energy investment grow by 27% to reach $74.5 billion in 2018, helped by the financing of five offshore wind projects in the billion-dollar-plus category (BNEF, 2019; Energy charts, 2019). Led by investments in both wind farms and solar arrays, the clean energy investment in the US rose by 12% to reach $64.2 billion in 2018 (BNEF, 2019; EIA, 2019). In Australia, the investment in clean energy in 2018 reached over $25.2 billion, which was associated with 14,510 MW of new renewable energy capacity and the direct creation of 13,658 jobs (Clean Energy Council, 2019).

In many countries, base-load coal power plants are being closed as part of national GHG reduction schemes (Lund and Mathiesen, 2009). In wholesale electricity markets with a high percentage of intermittent renewable generation, the closure of base-load power plants may lead to higher electricity prices and increased volatility, which would expose the market participants to a high level of financial risk. Over the past 5 years, 11 coal-powered generators have been closed in Australia's National Electricity Market (ANEM) (Table 2). One example of the crisis in action is the closure of the Hazelwood Power Station, which slashed

Table 1: Solar and wind generation (in GWh) and yearly growth rates (%) for Australia, Germany and the US from 2008–2018

Countries	Renewable fuels	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Australia	Solar(GWh)	20	60	310	1090	2070	3140	4020	5000	6020	6840	10050
	Growth		200.00%	416.67%	251.61%	89.91%	51.69%	28.03%	24.38%	20.40%	13.62%	46.93%
	Wind (GWh)	910	3780	4470	5680	6360	8000	8510	10050	11190	11270	14300
	Growth		315%	18%	27%	12%	26%	6%	18%	11%	1%	27%
Germany	Solar (GWh)	4420	6583	11729	19599	26380	31010	36056	38726	38098	39401	45750
	Growth		48.94%	78.17%	67.10%	34.60%	17.55%	16.27%	7.41%	–1.62%	3.42%	16.11%
	Wind (GWh)	41380	39240	38550	49860	51680	52740	58500	80620	79920	105690	111460
	Growth		–5.17%	–1.76%	29.34%	3.65%	2.05%	10.92%	37.81%	–0.87%	32.24%	5.46%
US	Solar (GWh)	76	157	423	1,012	3,451	8,121	15,250	21,666	32,670	50,017	63,012
	Growth		106.58%	169.43%	139.24%	241.01%	135.32%	87.78%	42.07%	50.79%	53.10%	25.98%
	Wind (GWh)	55360	73886	94652	120177	140822	167840	181655	190719	226993	254303	274952
	Growth		33.46%	28.11%	26.97%	17.18%	19.19%	8.23%	4.99%	19.02%	12.03%	8.12%

Figure 1: Global new investment in clean energy ($bn)

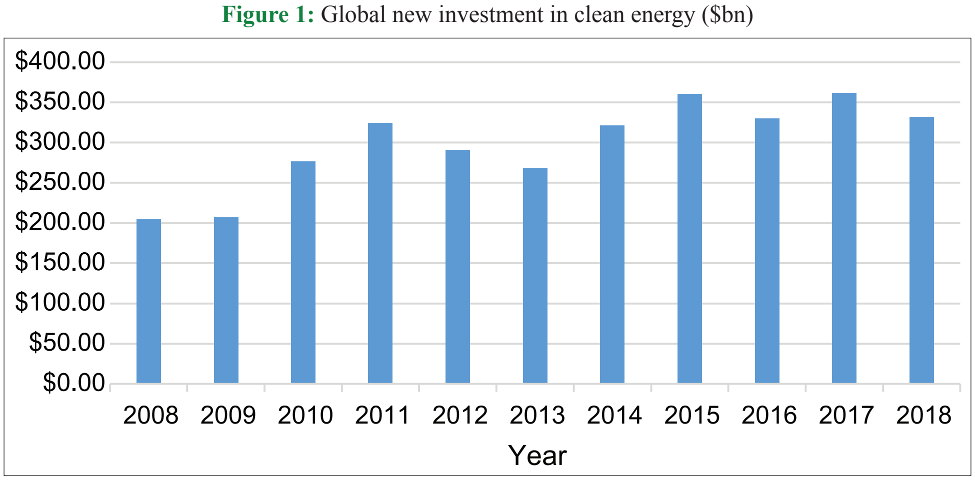


Table 2: The coal-fired power stations that have closed in recent years in Australia

Facility name	Region	Technology	Generator capacity (MW)
Angelsea	VIC	Brown Coal	165
Callide A	QLD	Black Coal	60
Collinsville	QLD	Black Coal	186
Energy Brix	VIC	Brown Coal	195
Hazelwood	VIC	Brown Coal	1640
Munmorah	NSW	Black Coal	600
Northern	SA	Brown Coal	730
Playford B	SA	Brown Coal	480
Redbank	NSW	Black Coal	150
Swanbank B	QLD	Black Coal	500
Wallerawang	NSW	Black Coal	1000

VIC: Victoria, QLD: Queensland, NSW: New South Wales, SA: South Australia.
Source: OpenNEM

Victoria's energy supply by 22% and caused the weighted average wholesale price to increase from \$52/MWh to \$96/MWh in one calendar year (Anderson, 2017).

Due to all the above, it is now widely believed that wholesale electricity price increases are related to the increased penetration of renewables as well as to recent coal-fired power plant closures. The aim of the present study is to examine the behaviour of international electricity markets in terms of the impact of solar and wind pricing on the global electricity spot and options markets, with a particular focus on the markets of Australia, Germany and the US. The study will conduct a multivariate analysis to examine the causal nature of the markets, particularly the relationship that may exist between the solar and wind prices and the electricity spot and options prices in each of the investigated countries. Additional information concerning the dynamics of the electricity, solar and wind prices will allow for a better understanding of the flow of pricing information among the markets. To generate this information, a vector autoregression (VAR) will be performed to examine the extent of the dynamic interactions that occur between the solar and wind prices and the electricity spot and options prices.

Moreover, the present study will conduct a multivariate analysis to examine the Granger causal nature of the markets, particularly the relationship that may exist between the solar and wind prices and the electricity spot and options prices in each of the investigated countries. Additionally, the impulse response function (IRF) will be used to measure the duration and the speed of the interactions that occur between the Australian, German and US electricity markets. Further, the extent to which those three electricity markets influence each other will also be examined using forecast error variance decomposition (FEVD).

This study makes two important contributions to the literature. First, in light of the current dearth of research concerning the dynamic relationships that exist between solar and wind pricing and the electricity spot and options markets, the present study fills a gap in the literature by disentangling the effects of solar and wind pricing on the "global" electricity spot and options markets using VAR models. The markets of Germany, Australia and the US are being used as proxies/examples for the global markets. This paper, therefore, provides valuable knowledge regarding the extent of both the integration and the linkages among the electricity markets in Australia, Germany and the US. Second, the results of the present study offer useful practical contributions for investors and policymakers, as additional knowledge concerning the linkages among the global electricity markets should prove highly valuable for them. Such knowledge is important for investors because the benefits derived from the international electricity markets depend on the extent of the linkages between the different markets, while it is valuable for policymakers due to its potential to help improve market efficiency.

The remainder of this paper is organized as follows. Section 2 introduces the relevant prior literature and situates the present paper in relation to it. Section 3 outlines the methodology employed in this study, while section 4 describes the utilised data sources. Section 5 presents the empirical research results, while section 6 discusses the findings and offers a conclusion to the study.

2. LITERATURE REVIEW

As the share of renewable electricity is increasing worldwide, researchers have sought to estimate the effect of renewable energy, especially wind and solar energy, on the global electricity markets using historical data. In this regard, see the work of Forrest and MacGill (2013), Worthington and Higgs (2017) and Csereklyei et al. (2019) concerning Australia; the work of Würzburg et al. (2013) and Cludius et al. (2014) concerning Germany; and the work of Woo et al. (2011) and Kaufmann and Vaid (2016) concerning the US. These studies use a variety of econometric methodologies and identify the negative effect of renewables on electricity prices.

According to de Menezes et al. (2016), the prior studies regarding electricity market integration can be divided into the following categories: (i) investigations of electricity market integration, (ii) assessments of electricity and fuel price convergence and (iii) investigations of electricity and renewable energy integration.

The first category concerns electricity market integration, which has been studied by numerous researchers (e.g., Bunn and Gianfreda, 2010; Higgs, 2009; Park et al., 2006). In relation to the ANEM, Higgs (2009) examined the inter-relationships between the wholesale spot electricity prices of four regional electricity markets, as well as the impact of the identified inter-connectivity on the electricity pricing dynamics, using half-hourly prices for the period 1 January 1999 to 31 December 2007. The examination was performed using three different multivariate generalized autoregressive conditional heteroscedasticity (MGARCH) models. Higgs (2009) concluded that inter-relationships exist between the well-interconnected markets.

In a European case study, Bunn and Gianfreda (2010) investigated the integration and shock transmissions across various European (Germany, France, Spain, Netherlands and the United Kingdom) electricity spot and forward prices by means of correlation analysis, Granger causality testing and cointegration analysis. The dynamics of the shocks for the prices and the squared logarithmic returns (as a proxy of volatility) were investigated using impulse response functions (IRFs) in a VAR for the spot prices and a vector error correction model (VECM) for the forward prices. The findings indicated that there was evidence of market integration, which was increasing over time, despite an underlying inefficiency in each market with respect to the convergence of the forward and spot prices.

In a US case study, Park et al. (2006) investigated the electricity spot price behaviour by testing 11 US markets for the period of February 26, 1998 to December 20, 2002. The study employed a VAR model, and they found that the relationships among the markets varied according to the time frame. Contemporaneously, the western US markets were separated from both the eastern markets and the Electricity Reliability Council of Texas. In the case of longer time frames, the separations disappeared, although it should be noted that the electricity transmission between the regions was found to be limited.

The second category of studies concerns electricity and fuel price convergence. Several prior studies have addressed the associations between the prices of different fuels (e.g., crude oil prices, coal prices and uranium prices) and electricity prices (Asche et al., 2006; Bernal et al., 2019; Ferkingstad et al., 2011; Mjelde and Bessler, 2009; Monteiro et al., 2016). For example, Mjelde and Bessler (2009) used weekly data from the US to investigate the dynamic price information flows among electricity wholesale spot prices and the prices of major fuel sources for electricity generation, namely natural gas, uranium, coal and crude oil. They used a VECM framework and concluded that, in the short run, contemporaneous time-peak electricity prices exerted a significant influence on natural gas prices. In the long run, they found that the prices of all the fuel sources influenced the electricity prices.

In a similar study, Ferkingstad et al. (2011) investigated the dynamic relationships between the prices of the major fuel sources for electricity generation and the Northern European electricity spot prices. The authors applied time series models using weekly Nordic and German electricity prices, as well as the oil, gas and coal prices. The German wind power and Nordic water reservoir levels served as exogenous variables. The authors estimated a Granger causality model for the price dynamics for both contemporaneous and lagged relationships. The results showed that the Nordic and German electricity prices were interlinked through the gas prices. In the long run, the electricity prices and the British gas prices adjusted themselves to establish the equilibrium price level, as the oil, coal, continental gas and EUR/USD variables were all found to be weakly exogenous.

The third category concerns the associations between the electricity markets and renewable energy. Many studies have examined the relationship between the global electricity markets and renewable energy (Ata, 2018; Gianfreda et al., 2016; Keppler et al., 2016). For instance, Keppler et al. (2016) investigated the impacts of renewable energy production (wind and solar PV) and market coupling on the convergence of the French and German electricity prices for the period November 2009-June 2013. They concluded that an increased supply from intermittent renewable energy sources often led to interconnection congestion and, hence, to price divergence, while market coupling strengthened the price convergence. This finding highlights the importance of investments in both interconnection capacities and market coupling during times of subsidised and prioritised feed-in for intermittent renewables. Further, Gianfreda et al. (2016) examined the relationship between the growth of renewable energy sources and the European power market integration. Their results indicated that the investigated European Union (EU) countries were becoming less integrated as the renewable energy sources increased.

Moreover, Ata (2018) used VAR models to examine the relationships between renewable energy consumption and electricity prices in the United Kingdom, Turkey and Nigeria using data from 1990 to 2012. The empirical results suggested that (i) there was unidirectional causality running from the electricity prices to renewable energy consumption in Turkey, (ii) there was a unidirectional causal link between renewable energy consumption and the electricity prices in Nigeria, and (iii) there was bidirectional causality in the relationship between renewable energy consumption and the electricity prices in the United Kingdom. The results concerning the impulse response functions indicated that renewable energy consumption in the three case study countries responded positively and significantly to a 10% deviation in the electricity prices. More specifically, the response was 0.09% in the short run and 0.05% (negatively) in the long run. The results of the FEVD analysis suggested that 0.2% of the fluctuations in the electricity prices were explained by a 2% deviation in the renewable energy consumption shock in the short run, while a 100% deviation explained approximately 5.6% of the fluctuations in the electricity prices in the long run.

This section has provided an overview of the major studies to have examined the nature and effects of renewable energy on the global electricity markets as well as on the electricity market integration. The majority of prior studies (Cludius et al., 2014; Csereklyei et al., 2019; Kaufmann and Vaid, 2016) examined the effects of solar and wind generation, rather than the effects of pricing, and they noted such effects to be generally and consistently associated with reduced electricity prices. Research into the effects of solar and wind pricing on the electricity markets is still required in terms of the spot and options prices. Further, the existing empirical research (Ferkingstad et al., 2011; Mjelde and Bessler, 2009) has shown that multivariate models can be used to decipher the dynamic interactions that occur between the electricity wholesale prices and the prices of the major fuel source (e.g., natural gas, uranium, coal and crude oil) using the VAR and VECM approaches. Therefore, the present study aims to fill the identified gap in the literature via an in-depth examination of the effects of solar and wind pricing on the electricity spot and options markets in Australia, Germany and the US for the period from January 2006 to March 2018 using VAR models.

3. METHODOLOGY

The present study examines international electricity market behaviour in terms of the impact of solar and wind pricing on the Australian, German and US spot and options markets by means of a VAR analysis (Sims, 1980). As previously stated, the investigation particularly focuses on the extent, speed and duration of the interactions among the three markets based on Granger causality, impulse response and variance decomposition analyses.

3.1. Vector Autoregression Model

This study employs a VAR approach to capture the dynamic interactions that occur between the Australian, German and US electricity markets. The VAR approach imposes a minimum theoretical demand on the utilised model's structure, and it requires only the variables and the largest number of lags to capture most of the variables' inter-effects. A number of examples of this approach can be found in the literature (Alsaedi and Tularam, 2019; Hassan and Tularam, 2018; Reza et al., 2017; Wong and El Massah, 2018). This study estimates a multivariate form of time series VAR by using a number of select variables within the VAR system. In a time series analysis that is observed to be multivariate, the variable (y_t), which consists of n variables, is characterised by a VAR model of an autoregressive order that is $\leq p$

$$y_t = M_o + \sum_{k=1}^{p} M_j y_{t-k} + \tau_t, \quad (1)$$

where y_t is an ($n \times 1$) matrix, that is, a column vector of daily, weekly, monthly, quarterly or yearly time series data, while M_0 and M_j are ($n \times 1$) and ($n \times n$) matrix coefficients, respectively. The variable p is the lag length and e_t is a column vector ($n \times 1$) of serially uncorrelated error value terms. The j^{th} term of M_j is used to estimate the immediate influence on the i^{th} value of a variation in the changes to the j^{th} value during k periods. The i^{th} component of t is the innovation of the i^{th} value, which cannot be forecasted based on past values of other variables in the system.

3.2. Granger Causality Analysis

The use of a Granger causality analysis (Granger, 1969) enables this study to examine the causal linkages between the Australian, German and US electricity markets. Stated in simple mathematical terms, the utilised Granger causality test is of the following kind: variable X does not Granger cause variable Y if, and only if, forecasts of Y based on the universe (U) of forecasters are no better than forecast of Y based on $U-$ [X], that is, the universe with X omitted.

More generally, where ($y_{1t}, y_{2t}, \ldots y_{nt}$) represents n variables: "y_{2t} granger-causes y_{1t} if past values of y_{2t} help in predicting y_{1t} in the presence of past values of y_{1t}". In other words, given:

$$y_{1t} = c_1 + \alpha_1 y_{1t-1} + \cdots + \alpha_p y_{1t-p} + \beta_1 y_{2t-1} + \cdots + \beta_p y_{2t-p} + \varepsilon_{1t} \quad (2)$$

test the following: H_0: $\beta_1 = \ldots = \beta_p = 0$ (no causality from y_{2t} to y_{1t}) using an F-test. If the null hypothesis is not rejected, then y_{2t} does not Granger cause y_{1t}. In a similar manner, to see whether y_{1t} Granger causes y_{2t}, use:

$$y_{2t} = c_1 + \alpha_1 y_{1t-1} + \cdots + \alpha_p y_{1t-p} + \beta_1 y_{2t-1} + \cdots + \beta_p y_{2t-p} + \varepsilon_{1t} \quad (3)$$

and test H_0: $\alpha_1 = \ldots = \alpha_p = 0$ (no causality from y_{1t} to y_{2t}) using an F-test. If the null hypothesis is not rejected, then y_{1t} does not Granger cause y_{2t}

3.3. Impulse Response Analysis

The impulse response method (Pesaran and Shin, 1998) is used to measure the duration and speed of the interactions between the Australian, German and US electricity markets by tracing the effects of a shock to one endogenous variable on the other variables within the VAR model. The dynamic relationships between the variables are captured by the impulse response function. The vector moving average process can be used to represent the VAR as follows:

$$y_t = \omega + \sum_{i=1}^{\infty} \Phi_i \tau_{t-i}, \quad (4)$$

where ω is the mean of the process, which is equal to $\Theta_0 \left(I_m - \Theta_1 - \cdots - \Theta_p \right)^{-1}$. The MA matrix Φ_i consists of responses intended to predict the errors of τ_t that occurred i periods ago. If the contemporary residual relationship is high, it is difficult to interpret the responses.

Cholesky decomposition was used to analyse the orthogonalised shocks obtained using $\sum_\tau$. As the outcome of the impulse response analysis (IRA) could possibly rely on the ordering of the variables, generalised impulse responses were used (Pesaran and Shin, 1998). According to the latter method, the shocks are orthogonalised by looking at a shock in variable k and then integrating out the influences of other shocks by using the distribution of the errors. Thus, the correlations amongst τ_t components are considered. If τ_t has a multivariate normal distribution, it can be illustrated as

$$E\left(\tau_{kt} | \delta_k\right) = \left(\sigma_{1k}, \sigma_{2k}, \cdots, \sigma_{nk}\right)^T \sigma_{kk}^{-1} \delta_k = \sum_{\tau} e_k \sigma_{kk}^{-1} \delta_k \quad (5)$$

where σ_{nk} represents the elements of $\sum_\tau$ and e_v is a selection vector ($k \times 1$) with a 1 in position k and a 0 elsewhere. Therefore, the response vector to a shock in variable k that occurred i periods ago is shown in the following equation:

$$\frac{\Phi_i \Sigma_\tau e_v \delta_k}{\sigma_{kk}} = \frac{\Phi_i \Sigma_\tau e_v}{\sqrt{\sigma_{kk}}} \cdot \frac{\sigma_v}{\sqrt{\sigma_{kk}}} \quad (6)$$

where δ_k is then scaled to achieve a standard deviation of size 1 and the setting $\delta_k = \sqrt{\sigma_{kk}}$ yields the following equation:

$$\vartheta_k\left(i\right) = \frac{\Phi_i \Sigma_\tau e_{kk}}{\sqrt{\sigma_{kk}}}, \text{ for } i = 0, \cdots, h \quad (7)$$

which provides a generalised impulse response of the variables in y_i to a shock in variable k that took place i periods ago. The IRA can be uniquely estimated, and it can take full account of the historical correlation patterns observed amongst the different shocks. Unlike the orthogonalised impulse responses, these patterns are invariant to the variable order in the VAR.

3.4. Variance Decomposition Analysis

A forecast error variance decomposition (FEVD) is another familiar tool for appraising multivariate time series models. The FEVD shows how the Australian, German and US electricity markets influence each other within the context of the VAR method. A FEVD decomposes the variation in an endogenous variable into the component shocks to the other endogenous variables within the VAR. The generalised impulse analysis aids in the derivation of the error FEVD. Meanwhile, the error terms are associated with uncertainty, as even a perfect model includes ambiguity regarding the realisation of y_t. A FEVD is useful for decreasing the uncertainty in one equation related to the variance of the error terms in all the equations. Further, a FEVD concerns the proportion of the h-step prediction error variance of variable i that is accounted for through the innovations of variable j within the VAR (Pesaran and Shin, 1998).

Denoting the ij^{th} part of the coefficient of the orthogonalised impulse response matrices, Θ_K by Γ_{ij}, the variance of the forecast error is given as

$$\sigma_t^2 = \sum_{k=0}^{h-1}\left(\Gamma_{1,k}^2 + \Gamma_{2,k}^2 + \cdots + \Gamma_{K,k}^2\right) = \sum_{j=0}^{T}\left(\Gamma_{tj,0}^2 + \Gamma_{tj,1}^2 + \cdots + \Gamma_{tj,h-1}^2\right) \quad (8)$$

The second method used to perform the FEVD is interpreted as the contributions of variable j to the h-step prediction error variance of variable t. Therefore, dividing the above terms by σ_t^2 provides the contribution percentage of variable j to the h-step prediction error variance of variable t (Lütkepohl, 2005):

$$\omega_{tj}\left(h\right) = \frac{\Gamma_{tj,0}^2 + \Gamma_{tj,1}^2 + \cdots + \Gamma_{tj,h-1}^2}{\sigma_t^2} \quad (7)$$

However, to conduct an analysis of the generalised prediction error variance, the form proposed by Pesaran and Shin (1998) was used in this study, as shown below:

$$\Psi_{ij}\left(k\right) = \frac{\sigma_{ij}^{-1}\sum_{I=0}^{K}\left(e_i^{'}\Phi\Sigma_\tau e_j\right)^2}{\sum_{i=0}^{k} e_i^{'}\Phi_\tau\Phi_i^{'}e_j} \quad (9)$$

4. DATA SOURCES

This study investigated the integration among the international electricity markets and the solar and wind prices, with a particular focus on Australia, Germany and the US. The dataset consisted of monthly observations, while the sample covered the period from January 2006 to March 2018. The choice of study period was constrained by the availability of time series data concerning the solar and wind electricity prices. All the variables are expressed in US$/MW.

The time series data concerning the spot electricity prices were collected on a monthly basis from the Australian Energy Market Operator (AEMO) for Australia, from the European Power Exchange (EPEX SPOT) for Germany, and from the US Energy Information Administration (EIA) for the US. The data concerning the options prices (closing prices) were collected from the Electricity Futures and Options (ASX) index for Australia. The other data were sourced from Bloomberg as follows: (a) for the options prices, from the Phelix Base Month Future and PJM Calendar Month LMP Option contracts for Germany and the US, respectively; (b) for the solar prices, from the MAC Global Solar Energy Index; and (c) for the wind prices, from the ISE Global Wind Energy Index. Table 3 presents the variables used in this study.

5. RESULTS

5.1. Data Preliminaries

The examination of the time series data began with the gathering of descriptive statistics, which served to introduce the variables used in this study as well as to evaluate them as to the means, medians, maximums, minimums, standard deviations, skewness, kurtosis, Jarque–Bera statistics and p-values from January 2006 to March 2018. Table 4 shows that the highest mean average of the electricity spot prices was seen in the case of the US ($51.11/MW), while the highest mean average of the electricity options

Table 3: Descriptions of the variables and data sources

Countries	Variables	Explanation	Data sources
Australia	Spot	The average monthly prices for the five market regions within the ANEM, namely New South Wales (NSW), Queensland (QLD), South Australia (SA), Victoria (VIC), and Tasmania (TAS).	AEMO
Germany	Spot	The average monthly prices for the EXAA supply areas in the three Austrian trading zones (APG, TIWAG and VKW) as well as the two control areas in Germany, namely the E.ON and RWE zones. Trading on the EXAA is possible for all five supply zones. The EXAA spot trading includes more than 65 electricity traders from over 14 countries on the Energy Spot Market. Baseload (01-24) is one of the main block products on the EEXA for the Austria/Germany delivery area.	EPEX
US	Spot	The wholesale monthly spot price for the PJM Interconnection, LLC, which administers the largest electricity market in the world, serving more than 44 million customers in Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and Washington, D.C.	EIA
Australia	Option	The average monthly prices of contracts with non-zero trading volumes for the four market regions in the ANEM, namely NSW, QLD, SA and VIC.	ASX
Germany	Option	The Phelix Base Month Option and the respective subsequent six delivery months for the German market.	Bloomberg
US	Option	The average monthly prices of the PJM Calendar Month LMP Option contracts.	Bloomberg
Global	Solar	The MAC Global Solar Energy Index tracks globally listed public companies that specialise in providing solar energy products and services.	Bloomberg
Global	Wind	The ISE Global Wind Energy Index is a quintile-based modified capitalisation weighted index tracking public companies that are active in the wind energy industry based on an analysis of those companies' products and services.	Bloomberg

prices was seen in the case of Germany ($71.14/MW) over the sample period. The standard deviations of the electricity prices range from $3.46 (Australian options) to $316.33 (solar).

Interestingly, negative spot electricity prices were noted in a number of electricity markets. For example, Table 4 shows the minimum value of the electricity spot prices in Germany to be $-12.02/MW. According to Gianfreda et al. (2018), negative prices emerging in the day-ahead, intra-day and balancing markets are considered to be signals of scarce downward flexibility, which occurs when a low load is combined with a high non-programmable renewable energy sources (RES) supply.

The distributional properties of the spot, options, solar and wind electricity price series all appear to be non-normal. All the variables are significantly positively skewed, ranging from 1.20 (Australian spot prices) to 2.62 (US spot prices), thereby indicating the greater likelihood of large price increases than of price falls. The kurtosis, or degree of excess, is also large, ranging from 3.24 for the Australian options prices to 13.18 for the US spot prices. As the kurtosis in all the electricity markets exceeds three, the distributions are noted to be leptokurtic (fat-tailed). The calculated Jarque–Bera statistics and the corresponding p-values, as shown in Table 4, test the null hypothesis that the distribution of the spot, options, solar and wind electricity prices is normal. All the $P < 0.01$ level of significance, except for the Australian options prices, indicating that the null hypothesis is rejected. These spot, options, solar and wind electricity prices are thus not well approximated by the normal distribution.

5.2. Analysis Based on Correlations

Table 5 shows the results of the preliminary analysis of the expected correlations amongst the variables. A correlation matrix presents the strength of the relationship(s) between the variables of interest. The correlation coefficients between the solar and spot electricity prices in Germany and in the US was $r = 0.44$ and $r = 0.53$, respectively, at a 1% level of positive significance. However, the correlation results indicate that the solar electricity prices were negatively correlated with the Australian spot electricity prices. Moreover, a significant relation was evident between the wind electricity prices and the US spot electricity prices ($P < 0.01$). The correlation coefficients between the spot electricity prices (Australia and Germany) and the wind electricity prices were weak and not statistically significant. However, correlation (1% significance) was found between the spot electricity prices in Germany and the US.

As can also be seen in Table 5, the solar electricity prices were significantly positively correlated with the options electricity prices in Germany and the US at 1% significance levels. Further, a significant relation was evident between the wind electricity prices and the options electricity prices in the US ($r = 0.61$, $P < 0.01$), in Germany ($r = 0.41$, $P < 0.01$) and in Australia ($r = 0.17$, $P < 0.05$). Furthermore, correlation (1% significance) was found between the wind and solar electricity prices.

Table 4: Descriptive statistics

	Mean	Median	Max.	Min.	SD	Skewness	Kurtosis	J-B	Probability
Spot electricity prices									
AUS	44.2	37.47	126.87	17.71	20.08	1.20	4.8	55.22	<0.0001
GER	49.1	44.22	172.7	-12.02	24.02	1.52	7.72	193.22	<0.0001
USA	51.11	44.43	186.89	24.15	24.57	2.62	13.18	803.70	<0.0001
Options electricity prices									
AUS	8.98	9.05	17.33	1.26	3.46	0.41	3.24	4.4	0.11
GER	71.14	64.53	204.39	28.17	29.98	1.61	6.41	134.79	<0.0001
USA	51.52	45.53	140.88	29.13	18.1	1.74	7.3	187.48	<0.0001
Solar and wind electricity prices									
Solar	352.02	218.03	1548.2	65.73	316.33	1.51	4.71	73.87	<0.0001
Wind	152.94	137.91	342.77	67.1	61.94	1.45	4.49	64.84	<0.0001

Prices are in $ per MW; SD, standard deviation; JB, Jarque–Bera test statistic; AUS, Australia; GER, Germany; US, United States

Table 5: Correlation matrix

	Spot				
	AUS-spot	**GER-spot**	**US-spot**	**Solar-price**	**Wind-price**
AUS-spot	1.00				
GER-spot	−0.16**	1.00			
USA-spot	−0.10	0.26***	1.00		
Solar	−0.16**	0.44***	0.53***	1.00	
Wind	0.13	0.24	0.43***	0.86***	1.00
	Options				
	AUS-option	**GER-option**	**US-option**	**Solar-price**	**Wind-price**
AUS-option	1.00				
GER-option	0.004	1.00			
USA-option	−0.17**	0.67***	1.00		
Solar	−0.07	0.66***	0.73***	1.00	
Wind	0.17**	0.41***	0.61***	0.86***	1.00

***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively

5.3. Vector Autoregressive Order Selection Criteria

An important preliminary step in any VAR analysis is to select the VAR lag order from the data. Selecting the optimal lag prior to constructing the VAR is important because a trade-off is involved in the selection of the number of lags. More specifically, too low a number of lags may lead to poor model specification, while too high a number may lead to the loss of too many degrees of freedom (Kireyev, 2000). In this study, the optimum lag of the VAR was determined based on the results of the Akaike information criterion (AIC). Based on Ivanov and Kilian's (2005) simulation design, for monthly VAR models, the AIC tends to produce the most accurate structural and semi-structural impulse response estimates for realistic sample sizes. Table 6 shows a significant lag length (one) for studying the effects of the solar prices on the spot electricity markets and a lag length (three) for studying the effects of the wind prices on the spot electricity markets. In addition, the lag selection process suggested a lag (three) for studying the effects of both the solar and wind prices on the spot electricity markets in Australia, Germany and the US. However, the results presented in Table 6 show a significant lag length (two) for studying the effects of the solar, wind and combined (solar and wind) prices on the options electricity markets in Australia, Germany and the US.

5.4. Vector Autoregressive System Stationarity and Stability

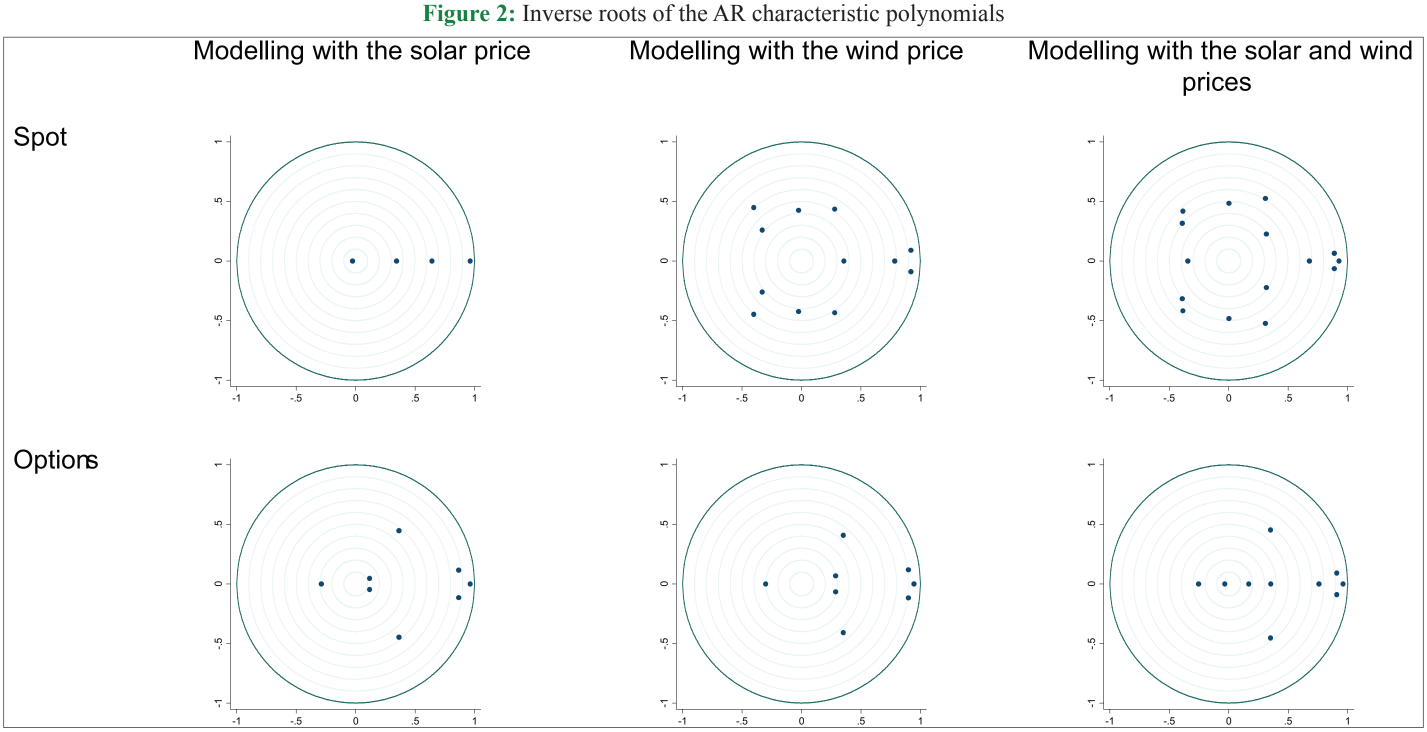
According to Lütkepohl (2005), the estimated VAR model is stable (stationary) if all the roots have a modulus of less than one and lie inside the unit circle. If the VAR is not stable, certain results (such as the impulse response) are not valid. To check the stability of our estimated parameters, we used the roots of the characteristic polynomials, as shown in Figure 2. The VAR satisfies the stability condition in all the models, and both the conditions are fulfilled. First, in our models there are kp roots, where k reflects the number of endogenous variables within the VAR model and p reflects the maximum number of lags that we have selected in our model. Second, all the roots have a modulus less than of one and lie within the unit circle. In other words, the results clearly indicate that the specified models are stable (stationary), as all the inverse roots of the characteristic AR polynomials have a modulus <1 and lie inside the unit circle.

Table 6: Optimal lag determination

Model	Lag 0	Lag 1	Lag 2	Lag 3	Lag 4
Spot					
Modelling with the solar price	41.07	37.63*	37.68	37.65	37.63
Modelling with the wind price	38.03	34.18	34.10	34.05*	34.08
Modelling with the solar and wind prices	50.30	44.73	44.72	44.670*	44.675
Options					
Modelling with the solar price	36.32	29.95	29.81*	29.85	29.95
Modelling with the wind price	33.38	26.43	26.23*	26.26	26.38
Modelling with the solar and wind prices	45.49	36.9	36.70*	36.74	36.84

*Denotes the lowest Akaike information criterion

Figure 2: Inverse roots of the AR characteristic polynomials



5.5. Vector Autoregressive Estimation Model

A VAR analysis was performed to determine which variables were significantly linked. Table 7 presents the results of the VAR analysis between the solar, wind and spot electricity prices. VAR(1) was used to assess the interaction between the solar prices and the electricity spot markets. The VAR results show that the solar price has a significant impact on the electricity spot prices in Germany and the US. The independent solar price variable (lag 1) is a significant variable (<1%) in terms of explaining the dependant variables, which are the electricity spot prices in Germany and the US. Further, VAR(3) was conducted to assess the interaction between the wind prices and the electricity spot markets. The VAR results indicate that the German spot prices (lag 2) and the Australian spot prices (lag 2) impact the US spot prices at <10% significance level. The results also suggest that the German spot prices (lag 3) have a negative effect on the wind prices.

Furthermore, VAR(3) was used to examine the interaction between the solar and wind prices and the electricity spot markets in Australia, Germany and the US. The results suggest that the solar prices (lag 1) impact the Australian spot prices at a 5% significance level, while the solar prices (lag 3) impact the US spot prices at a 5% significance level. The results also suggest that the wind prices (lag 3) impact the US spot prices at less than a 5% significance level. In addition, the German spot prices (lag 1) and US spot prices (lag 3) exhibit low negative impacts on the Australian spot prices.

Table 8 presents the results of the VAR analysis between the solar, wind and options electricity prices. VAR(2) was used to examine the relationship between the solar prices and the electricity options markets in Australia, Germany and the US. The independent solar price variable (lag 1) is a significant variable (<1%) in terms of explaining the dependant variable, which is the German options prices. Further, VAR(2) was conducted to assess the interdependence among the wind prices and the electricity options markets in Australia, Germany and the US.

The VAR results suggest that the wind prices (lag 1) influence the German options prices at a 5% significance level, while the wind

Table 7: VAR for the solar, wind and spot electricity prices

		AUS-spot	GER-spot	US-spot	Solar	Wind
Modelling with the solar price						
		AUS-spot	**GER-spot**	**US-spot**	**Solar**	
AUS-spot	L1	0.58***	−0.09	0.05	0.28	
GER-spot	L1	−0.18***	0.28***	0.1	−0.52*	
USA-spot	L1	0.06	0.20***	0.07	0.04	
Solar	L1	−0.001	0.02***	0.04***	0.99	
C		25.29	21.88	27.55	11.8	
Modelling with the wind price						
		AUS-spot	**GER-spot**	**US-spot**	**Wind**	
AUS-spot	L1	0.48***	0.003	0.1	0.02	
	L2	0.02	-0.16	−0.23*	−0.08	
	L3	0.15*	0.14	0.004	0.05	
GER-spot	L1	−0.15**	0.14*	0.14	−0.01	
	L2	0.07	0.25***	0.16*	−0.03	
	L3	−0.05	0.2**	−0.04	−0.20***	
USA-spot	L1	0.06	0.19***	0.11	−0.001	
	L2	−0.07	0.01	0.08	0.003	
	L3	−0.13**	0.01	−0.02	0.003	
Wind	L1	−0.01	0.07	0.16	1.31***	
	L2	0.07	−0.08	0.12	−0.44***	
	L3	−0.02	0.06	−0.16	0.11	
C		24.13	2.04	16.88	14.27	
Modelling with the solar and wind prices						
		AUS-spot	**GER-spot**	**US-spot**	**Solar**	**Wind**
AUS-spot	L1	0.45***	0.03	0.14	−0.06	0.04
	L2	0.001	−0.12	−0.16	−0.21	−0.03
	L3	0.12	0.18*	0.1	0.45	0.11*
GER-spot	L1	−0.13**	0.11	0.08	0.05	−0.05
	L2	0.09	0.22***	0.1	0.13	−0.06
	L3	−0.03	0.17**	−0.1	−0.92***	−0.23***
USA-spot	L1	0.07	0.17**	0.08	0.13	−0.03
	L2	−0.05	−0.02	0.02	−0.09	−0.02
	L3	−0.12**	−0.01	−0.06	−0.12	−0.03
Solar	L1	−0.05**	0.01	0.02	0.64***	−0.05***
	L2	0.05	−0.02	−0.05	0.2	0.05*
	L3	−0.01	0.04	0.07**	0.14	0.04*
Wind	L1	0.24	−0.03	−0.06	2.6***	1.47***
	L2	−0.15	0.07	0.43	−1.93*	−0.57***
	L3	0.02	−0.08	−0.44**	−0.58	−0.03
C		16.75	11.08	34.26	19.04	23.04

***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively

Table 8: VAR analysis of the solar, wind and options electricity prices

		AUS-option	GER-option	US-option	Solar	Wind
Modelling with the solar price						
		AUS-option	**GER-option**	**US-option**	**Solar**	
AUS-option	L1	1.21***	−0.05	−0.16	15.3**	
	L2	−0.26***	0.98	−0.08	−15.06**	
GER-option	L1	−0.002	0.41***	−0.10**	−0.27	
	L2	−0.01**	0.22***	0.08	−0.48	
USA-option	L1	0.002	0.04	0.75***	0.58	
	L2	0.01	−0.1	−0.34***	0.15	
Solar	L1	−0.001	0.04**	0.01	0.99***	
	L2	0.001	−0.01	0.01	−0.01	
C		0.81	10.04	24.6	14.69	
Modelling with the wind price						
		AUS-option	**GER-option**	**US-option**	**Wind**	
AUS-option	L1	1.21***	−0.62	−0.64	0.46	
	L2	−0.27***	1.34	−0.004	−1.13	
GER-option	L1	−0.002	0.50***	−0.04	−0.13	
	L2	−0.01**	0.28***	0.14***	0.03	
USA-option	L1	−0.01	0.06	0.75***	0.14	
	L2	0.002	−0.03	−0.33***	−0.16	
Wind	L1	−0.003	0.26**	0.12*	1.25	
	L2	0.01	−0.18	−0.02	−0.26	
C		0.73	−4.12	14.03	14.95	
Modelling with the solar and wind prices						
		AUS-option	**GER-option**	**US-option**	**Solar**	**Wind**
AUS-option	L1	1.21***	0.39	−0.37	7.45	−0.18
	L2	−0.27***	1.19	0.21	−5.79	−0.14
GER-option	L1	−0.002	0.37***	−0.1*	−0.04	−0.15**
	L2	−0.01*	0.16*	0.08	−0.4	0.01
USA-option	L1	0.001	0.06	0.74***	0.08	0.09
	L2	0.004	−0.05	−0.33***	0.55	−0.11
Solar	L1	−0.001	0.05	0.004	0.64***	−0.06***
	L2	0.001	0.01	0.02	0.32**	0.07***
Wind	L1	−0.001	0.02	0.09	2.8***	1.52***
	L2	0.004	−0.15	−0.09	−2.71***	−0.56***
C		0.67	17.54	23.94	−22.21	15.66

***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively

prices (lag 1) also influence the US options prices, albeit at less than a 10% significance level.

Moreover, VAR(2) was used to examine the relationships between the solar and wind prices and the electricity options markets in Australia, Germany and the US. The estimates of the VAR model show that the Australian options prices (lag 3) represents a significant variable (<10%) in terms of explaining the solar price, while the German options prices (lag 3) impact the solar prices at a 5% significance level. However, the results also suggest that there is a significant relationship between the solar prices (lags 1 and 2) and wind prices (lags 1 and 2), whereby each variable is statistically significant in terms of explaining changes in the other variable.

Using a VAR framework, we explore other interesting dynamic relationships among the solar, wind, spot and options electricity prices using tools such as Granger causality (GC), IRFs and FEVD for Australia, Germany and the US.

5.6. Granger Causality Test Results

The VAR models were also used to test the GC, that is, whether the lags of one variable explain the current value of certain other variable, as well as to describe the dynamics of the data (Brooks, 2019). The GC tests were performed to test the causal relationships between the solar and wind prices and the electricity spot and options markets in Australia, Germany and the US.

The GC test results are presented in Table 9. On the one hand, this study investigated whether the solar, wind and combined (solar and wind) prices Granger cause the electricity spot prices (or vice versa) in Australia, Germany and the US. On the other hand, this study also investigated whether the solar, wind and combined (solar and wind) prices Granger cause the electricity options prices (or vice versa) in Australia, Germany and the US.

We first performed a multivariate GC analysis in a VAR model to determine whether the solar price affected the spot electricity markets. It can be seen from Table 9 that the solar prices did indeed Granger cause the spot prices in both Germany and the US at a 1% level of significance, although no causality was noted from the US spot prices to the solar prices. However, the German spot prices influence the solar prices at a 10% significance level. Further, the German spot prices influence the Australian spot prices at a high (1%) significance level, while the US spot prices influence the German spot prices at a 1% significance level.

Table 9: Granger causality test results

	Spot						Options				
	Modelling with the solar price						Modelling with the solar price				
	AUS -spot	GER -spot	US -spot	Solar	Wind		AUS -option	GER -option	US -option	Solar	Wind
AUS-spot	-	9.78***	0.98	0.11		AUS-option	-	11.97***	1.67	1.8	
GER-spot	1.31	-	7.40***	8.74***		GER-option	5.21*	-	0.55	22.27***	
USA-spot	0.38	1.48	-	26.70***		USA-option	0.96	4.26	-	37.98***	
Solar	0.8	3.25*	0.02	-		Solar	4.56	4.69*	1.61	-	
	Modelling with the wind price						Modelling with the wind price				
	AUS -spot	GER -spot	US -spot	Solar	Wind		AUS -option	GER -option	US -option	Solar	Wind
AUS-spot	-	7.06*	7.41*		2.24	AUS-option	-	10.65***	0.98		2.49
GER-spot	3.03	-	7.11*		3.48	GER-option	2.77	-	0.14		10.35***
USA-spot	4.25	5.99	-		16.54***	USA-option	5.67*	8.94**	-		26.04***
Wind	1.17	18.88***	0.01		-	Wind	4.58	5.09*	2.4		-
	Modelling with the solar and wind prices						Modelling with the solar and wind prices				
	AUS -spot	GER -spot	US -spot	Solar	Wind		AUS -option	GER -option	US -option	Solar	Wind
AUS-spot	-	5.57	6.33*	5.59	5.43	AUS-option	-	6.06**	1.02	0.16	0.84
GER-spot	3.65	-	5.49	3.88	0.62	GER-option	9.94***	-	0.18	16.29***	4.79*
USA-spot	2.62	2.75	-	10.54***	5.11	USA-option	0.35	3.94	-	10.97***	0.79
Solar	1.42	9.21**	0.5	-	18.1***	Solar	1.43	1.48	1.29	-	14.25***
Wind	4.40	30.06***	1.31	27.59***	-	Wind	0.75	5.78*	1.2	10.45***	-

***, ** and * indicate significance at the 1%, 5% and 10% levels, respectively

In terms of whether or not the wind prices Granger cause the electricity spot prices (or vice versa), the GC tests show that there is unidirectional GC running from the wind electricity prices to the spot electricity prices in the US at a 1% (high) level of significance. Further, no causality is noted from the wind electricity prices to the spot electricity prices in either Australia or Germany. Moreover, the spot market variables (Germany and the US) were noted to affect the Australian spot market at a 10% (low) level of significance; however, the reverse was not true for both variables.

Additionally, we investigated whether the combined impact of the solar and wind prices Granger causes the electricity spot prices. The results suggest that there is one-way GC running from the solar price to the spot electricity price in the US at a 1% level of significance. The GC was medium to high (at the 5% and 1% significance levels) from the German spot prices to the solar and wind electricity prices, respectively. There is unidirectional GC running from the spot electricity prices in the US to the spot electricity prices in Australia at a 10% (low) level of significance.

The GC tests isolate either one- or two-way GC between the solar and wind prices and the electricity options markets in Australia, Germany and the US. These Granger causalities are shown in Table 9 based on the VAR model. First, we tested for GC between the solar prices and the electricity options markets. The results show that there is GC at the 1% (high) level of significance running from the solar prices to the options electricity prices in the US. There is two-way GC between the solar prices and the options electricity prices in Germany, while there is two-way GC between the options electricity prices in Germany and in Australia.

In addition, we explored the same Granger causal relations in the case of the wind power prices as well as the options electricity prices. The results clearly indicate that the wind prices Granger cause the options electricity prices in both Germany and the US at a 1% (high) level of significance. However, the German options electricity prices Granger cause the wind prices at a 10% (low) level of significance, and there is no causality noted from the US options prices to the wind prices. Additionally, there is unidirectional GC running from the options electricity prices in both German and Australia to the options electricity prices in the US at the 1% (high) and 5% (medium) significance levels, respectively.

Moreover, we investigated whether the combined impact of the solar and wind prices Granger causes the electricity options prices. The results suggest that the solar and wind prices Granger cause the options electricity prices in Germany at the 1% and 10% significance levels, respectively. Interestingly, reverse causalities were only noted from the options electricity prices in Germany to the wind prices at a 5% (medium) significance level. Further, GC was observed in both directions in relation to the options electricity prices in Australia and Germany. Additionally, the causality was noted to be bidirectional for the solar and wind prices at a 1% (high) level of significance.

5.7. Impulse Response Test Results

The results of the IRA were used to investigate the degree and manner of the interactions among those markets that are significantly linked. An IRA provides evidence as to how much and how quickly the movement of one market is transmitted to the other markets. This study conducted the IRA analysis in two ways: (1) an IRA was applied to determine the speed and duration of the interactions among the spot, solar and wind electricity prices in Australia, Germany and the US; and (2) an IRA was applied to measure the duration and speed of the interactions between the options, solar and wind electricity prices in the three countries of interest. The results of the generalised IRA are presented below as figures showing the impulse responses for the spot or options, solar and wind electricity prices, with the responses being plotted between 1≤t≤10 (Figures 3 and 4).

The IRA was first performed on the solar and spot electricity price variables, and the effects are shown in Figure 3. Relative to the impact of a solar price shock, the Australian spot prices first decreased and then rapidly increased at t = 3. In response to a solar price shock, the German spot prices did not move markedly in a positive direction and, in fact, moved in a negative direction. As a result of a single shock to the solar price, the US spot prices first increased and then rapidly decreased after t = 3. Further, in response to a spot price shock, the solar price moved markedly in a positive direction after t = 3 in the cases of the German and US spot prices, while in the case of the Australian spot prices, the solar price tended towards zero and did not respond.

With regards to the wind and spot electricity price variables, as a result of a single shock to the wind price, the Australian spot prices first decreased and then tended towards zero at $t = 6$, while the German spot prices moved markedly in a negative direction, and the US spot prices first increased and then rapidly decreased at t = 5. Further, in response to a spot price shock, the wind price moved markedly in a positive direction after t = 1 in the cases of the German and US spot prices, while the Australian spot prices did not markedly affect the wind price.

In the case of both the solar and wind prices and the spot electricity price variables, as a result of a solar price shock, the Australian spot prices moved in the negative direction at t = 1before returning to zero at t = 8. In addition, relative to the impact of a solar price shock, the German spot prices moved markedly in a negative direction, while the US spot prices first increased and then became negative from t = 4. In contrast, Figure 3 shows that the German and US spot prices markedly affected the solar price after t = 4 In response to a wind price shock, the Australian spot prices initially became negative, and then positive, before tending toward zero at t = 10, while the German and US spot prices moved markedly in a negative direction. However, Figure 3 shows that the spot prices of the three countries did not markedly affect the wind prices. Figure 4 shows the results of the IRA concerning the interactions between the options, solar and wind electricity prices in Australia, Germany and the US. Relative to the impact of a solar price shock, the Australian options prices initially decreased and then became positive for the subsequent period (2≤t≤8) before returning to being negative at t = 9. In response to a solar price shock, the German options prices moved markedly in a negative direction. On the contrary, the US options prices moved markedly in a positive direction. A shock in the Australian options prices did not affect the solar prices, while a single SD shock to both the German and US options prices resulted in the solar prices becoming positive after t = 1.

With regard to the wind and options electricity price variables, relative to the impact of a wind price shock, the Australian options

Figure 3: Impulse response spot, solar and wind graphs

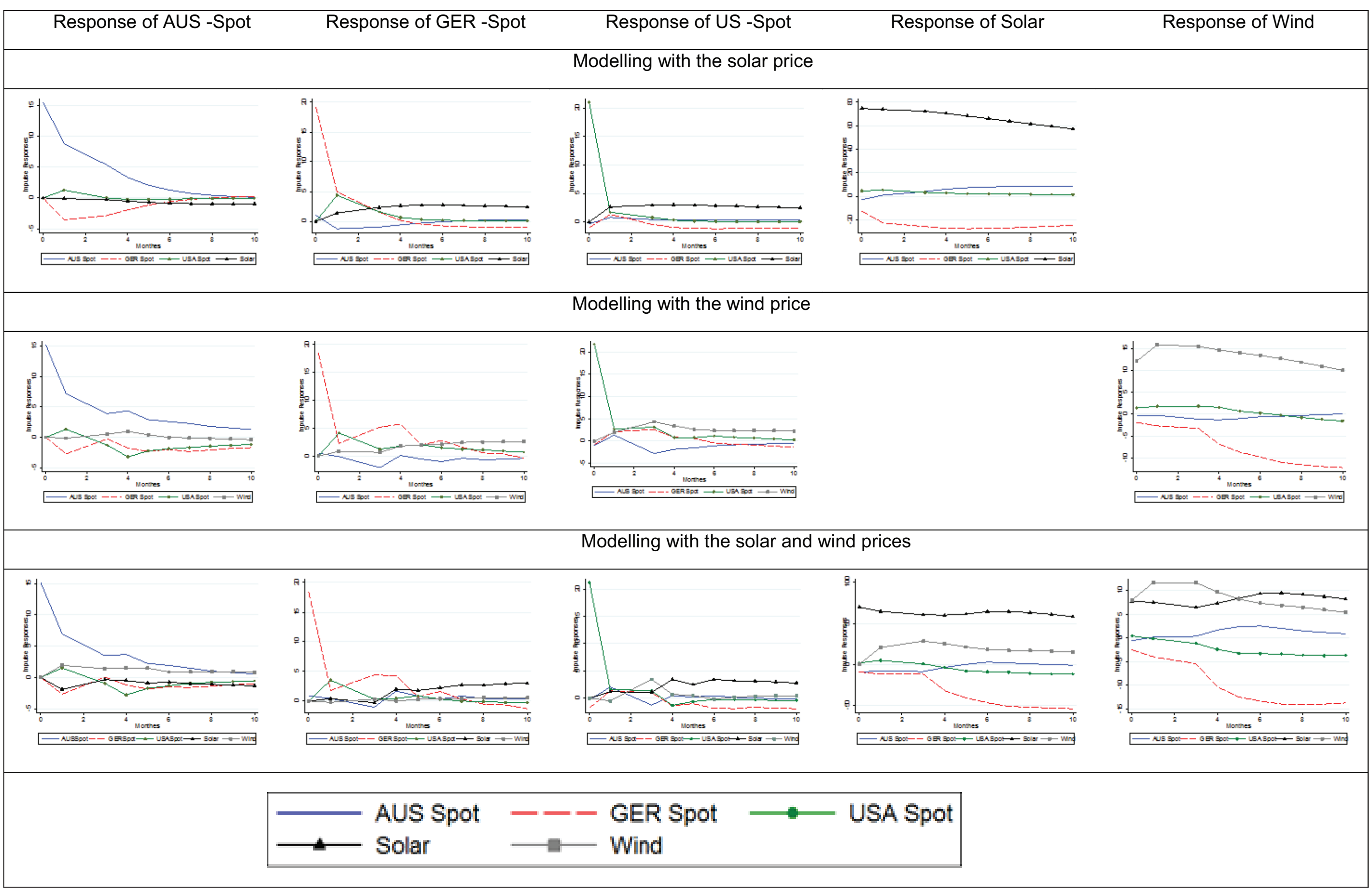
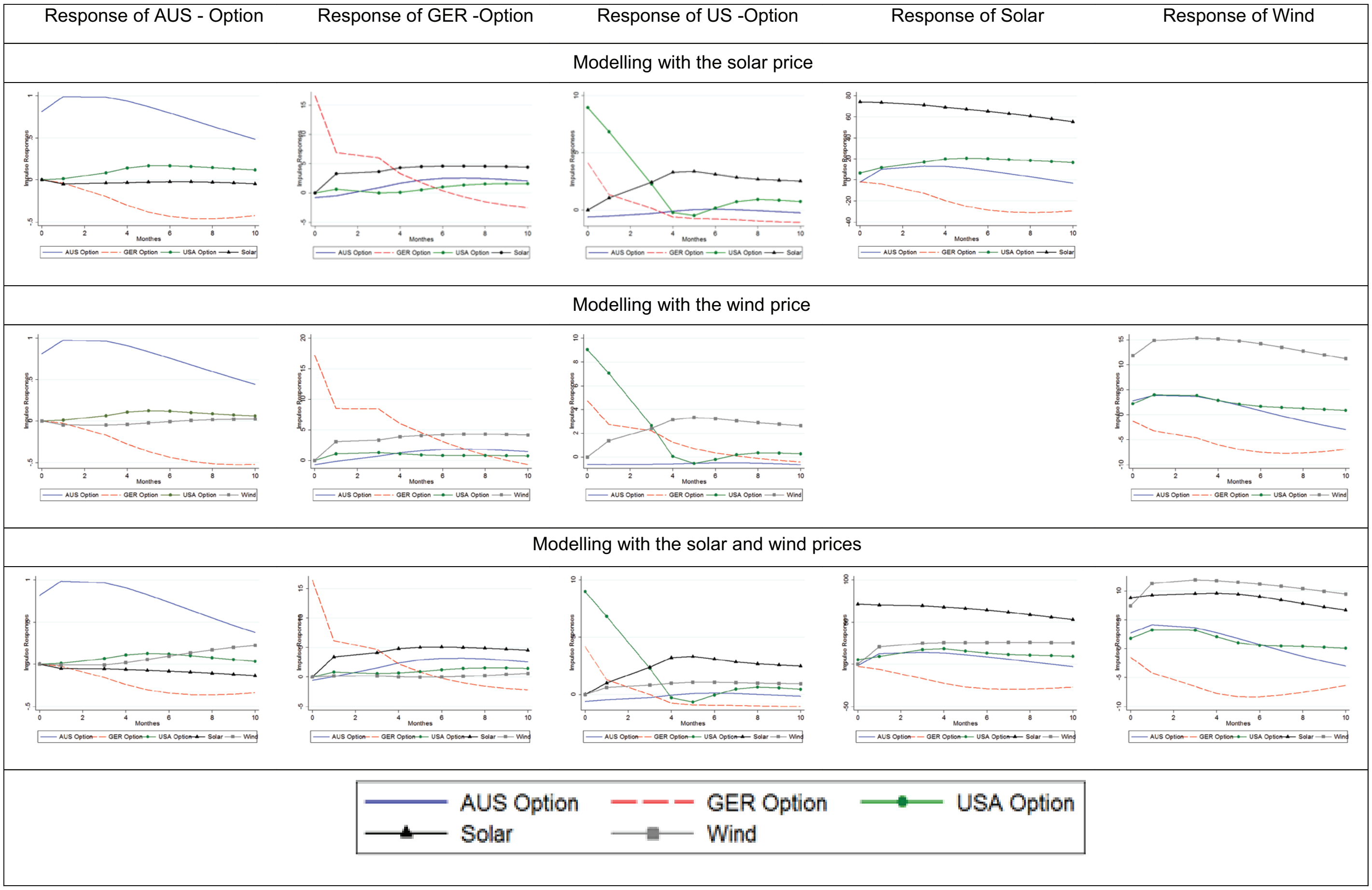


Figure 4: Impulse response options, solar and wind graphs



prices became positive for a few periods (1≤t≤6) before returning to being negative at t = 7. In addition, a single SD shock to the wind price resulted in a decrease in the German options prices and an increase in the US options prices. However, the wind prices were not significantly affected by the Australian options prices and, in the cases of the German and US options prices, the wind price variable increased in a positive direction.

For both the solar and wind and options electricity prices, as a result of a solar price shock, the Australian options prices first decreased and then rapidly increased at t = 2 before tending toward zero at $t = 9$. Further, one unit shock (an increase of one standard deviation) in the solar prices led to a sharp increase in the US options prices and a sharp decrease in the German options prices. Figure 4 shows the response of the German options prices to a shock in the solar price to be negative and to exhibit a downward trend, while the US options prices show a similar response, albeit in a positive and upward direction. Furthermore, in response to a wind price shock, the Australian options prices increased quickly for the subsequent period (1≤t≤) before returning to being negative at t = 7. The response of the wind prices to a unit shock in the German options prices was negative and, therefore, had a downward trend. A single SD shock to the wind price resulted in a t = 1 increase in the US options prices, which subsequently returned to zero at t = 6. However, shocks in the options prices (Australia, Germany and the US) did not markedly affect the wind prices.

5.8. Variance Decomposition Test Results

One important aspect of any VAR analysis concerns the ability to see how an innovation from one variable affects both itself and other variables. This can be achieved by applying FEVD. This study first investigated whether the respective movement of the solar, wind and spot prices significantly affected the price movement of the other variables in Australia, Germany and the US. Similarly, the study investigated whether the respective movement of the solar, wind and options prices significantly affected the price movement of the other variables in the three countries of interest.

The FEVD analysis results are presented in Table 10, where the dependent variables are placed in rows and the independent (or input) variables are placed in columns. The results are shown in terms of the percentage of forecast variance of a given variable in response to random shocks provided by other variables in the columns containing those independent variables. The numbers shown along the diagonal of each matrix indicate the self-forecast variance for a given variable, while the sum of the percentages for the other variables is the forecast variance due to those other variables.

In Table 10, in the solar and spot electricity prices section, it can be seen that for a forecast horizon of 10 months, the movement in the electricity spot prices in Australia, Germany and the US is explained by its own innovative shocks. The contribution of the solar prices to the spot electricity prices in Australia, Germany

Table 10: Variance decomposition analysis results

	Spot				
	Modelling with the solar price				
	AUS -spot	GER -spot	USA -spot	Solar	Wind
AUS-spot	93.48	5.65	0.39	0.48	
GER-spot	0.78	89.38	4.33	5.51	
USA-spot	0.24	1.24	91.36	7.17	
Solar	0.45	9.27	0.25	90.02	
	Modelling with the wind price				
	AUS -spot	GER -spot	USA -spot	Solar	Wind
AUS-spot	90.38	4.88	4.47		0.27
GER-spot	1.00	90.8	5.19		3.01
USA-spot	2.43	2.04	88.73		6.81
Wind	0.24	14.7	0.9		84.16
	Modelling with the solar and wind prices				
	AUS -spot	GER -spot	USA -spot	Solar	Wind
AUS-spot	89.1	3.56	3.25	1.58	2.51
GER-spot	1.11	92.38	2.9	3.5	0.12
USA-spot	1.05	2.4	89.17	5.42	1.96
Solar	1.00	13.76	0.55	78.13	6.56
Wind	0.66	27.18	1.56	28.51	42.09

	Options				
	Modelling with the solar price				
	AUS -option	GER -option	USA -option	Solar	Wind
AUS-option	91.22	7.52	1.14	0.11	
GER-option	2.91	81.59	0.6	14.90	
USA-option	0.41	11.71	72.03	15.85	
Solar	1.45	5.13	4.04	89.38	
	Modelling with the wind price				
	AUS -option	GER -option	USA -option	Solar	Wind
AUS-option	91.13	8.13	0.61		0.12
GER-option	1.3	87.38	0.77		10.55
USA-option	0.82	17.53	66.94		14.70
Wind	3.75	9.82	3.49		82.93
	Modelling with the solar and wind prices				
	AUS -option	GER -option	USA -option	Solar	Wind
AUS-option	93.07	5.25	0.65	0.46	0.57
GER-option	4.73	76.6	0.86	17.78	0.03
USA-option	0.34	11.88	70.92	15.01	1.86
Solar	1.69	5.55	2.61	82.88	7.27
Wind	3.8	13.39	2.15	35.60	45.06

and the US is 0.48%, 5.51% and 7.17% respectively. In addition, for a forecast horizon of 10 months, 0.45% of the movement in the solar prices is explained by changes in the Australian spot prices, 9.27% by changes in the German spot prices and 0.25% by changes in the US spot prices.

In the wind and spot electricity prices section, for a forecast horizon of 10 months, 90.38% of the movement in the Australian spot prices is explained by changes in the Australian spot prices, 4.88% by changes in the German spot prices, 4.47% by changes in the US spot prices and 0.27% by changes in the wind prices. The results also show that the contributions of the wind price to the German and US spot electricity prices are 3.01%, and 6.81%, respectively. Further, the variance decomposition of the wind prices reveals that the major changes in the wind prices are attributable to its own innovation, followed by the German spot prices (14.7%), over the 10-month period.

In the combined solar and wind prices and spot electricity prices section, the results show that the contribution of the solar price to the spot electricity price is 1.58% in the case of the Australian spot prices, 3.50% in the case of the German spot prices and 5.42% in the case of the US spot prices over the 10-month period. With regards to the solar price, for a forecast horizon of 10 months, 1.00% of the movement in the solar price is explained by changes in the Australian spot prices, 13.76% by changes in the German spot prices, 0.55% by changes in the US spot prices, 78.13% by changes in the solar prices and 6.56% by changes in the wind prices. The contributions of the wind price to the spot electricity prices in Australia, Germany and the US are 2.51%, 0.12% and 1.96%, respectively. In terms of the wind price, the contribution of the solar price is the most important, accounting for about 29% of the change, while the contribution of the German spot price is the second most important, accounting for roughly 28% of the change, and the US spot price accounts for about 2% of the.

The FEVD approach was also used to determine the extent of the variation, in percentage terms, between the solar, wind and options prices in Australia, Germany and the US. Table 10 presents the estimates for the variance decomposition that were derived from the estimated VAR model. In the solar and options electricity prices section, the results show that the contributions of the solar price to options electricity prices are 0.11% in the case of the Australian options prices, 14.90% in the case of the German options prices and 15.85% in the case of the US options prices over the 10-month period. Moreover, the variance decomposition of the solar prices reveals that the major changes in the solar price are attributable to its own innovation, while the contribution of the German options prices is 5.13% and that of the US options prices is 4.04% over the 10-month period.

In the wind and options electricity prices section, the empirical evidence indicates that the Australian options prices, the German options prices and the wind prices explain the US options prices by 0.82%, 17.53% and 14.70%, respectively. The results also show that 66.94% of the US options prices is explained by its own innovative shocks. In Table 10, the results further show that the contributions of the wind prices to the options electricity prices are 0.12% in the case of the Australian options prices, 10.55% in the case of the German options prices and 14.70% in the case of the US options prices over the 10-month period.

In the combined solar and wind prices and options electricity prices section, the contributions of the solar and wind prices to the Australian options prices are 0.46% and 0.57%, respectively, while the contributions of the solar and wind prices to the German options prices are 17.78% and 0.03% respectively, and the contributions of the solar and wind prices to the US options prices are 15.01% and 1.86%, respectively. In Table 10, the results also show that almost 35.60% of the future fluctuations in the wind price are due to shocks in the solar price, while 13.39% of the future fluctuations in the wind price are due to shocks in the German options price.

6. DISCUSSION AND CONCLUSION

The aim of this study was to examine international electricity market behaviour in terms of the impact of the solar and wind prices on the global electricity spot and options markets, with a particular focus on the markets of Australia, Germany and the US, using a VAR framework. Within this framework, we examined the GC, IRF and FEVD over the period from January 2006 to March 2018. In terms of the correlation analysis (Table 5), we found positive linear correlation between the renewable energy prices (solar and wind) and the electricity prices (spot and options), except for the correlations between the solar prices and the electricity spot and options prices in Australia. Fairly similar results were found by Reboredo and Ugolini (2018), who identified positive linear dependence between the renewable energy stock returns and the electricity price in the US and Europe.

The GC offers the justification for the predictive causal ability of models based on the available information criteria. The GC results presented in Table 9 indicated that, in most cases, there is one- or two-way causality between any pair of variables among the solar, wind, spot and options prices in Australia, Germany and the US. The results of the GC analysis showed that the German and US markets are significantly affected by solar and wind price changes. The analysis also revealed that solar and wind price changes are affected by the German spot and options prices, while the Australian, German and US electricity markets are generally interconnected. The solar and wind prices may play a role in such interconnections. This finding is in line with the findings of other studies (Ata, 2018; Kyritsis et al., 2017). The results obtained by Kyritsis et al. (2017) showed that there is statistically significant evidence of GC running from solar power generation and wind power generation to the electricity prices in Germany. In addition, Ata (2018) noted that there is bidirectional causality in the relationship between renewable energy consumption and electricity prices in the United Kingdom.

An IRA was conducted to determine the speed and duration of the interactions among the spot, options, solar and wind electricity prices in Australia, Germany and the US. The results of the IRA (Figures 3 and 4) indicated increasing integration among the variables during the studied period. The results further revealed that each variable responds efficiently to shocks from other variables, and they indicated that the electricity markets are not immune to global solar and wind price shocks. In a related study, Ata (2018) found that renewable energy consumption in the United Kingdom, Turkey and Nigeria responded positively and significantly to a 10% deviation in the electricity prices. More specifically, the response was 0.09% in the short run and 0.05% (negatively) in the long run. Additionally, according to Paschen (2016), the day-ahead spot prices in the German electricity spot market are decreasing over time due to shocks in the wind and solar power prices.

This study applied a FEVD analysis to investigate the relationships between the spot, options, solar and wind electricity prices in Australia, Germany and the US, as well as to reflect the percentage of the forecast variance for a particular variable that arises from random shocks from each variable. The FEVD results (Table 10) showed that a number of the studied variables are significantly influenced by the movements of other variables, causing different variables to become less open to the effects of others. However, the FEVD results also suggested that the spot and options electricity price shocks were mostly caused by their own innovations.

As noted in several previous studies (Ferkingstad et al., 2011; Mjelde and Bessler, 2009), global energy prices are cointegrated or linked. Here, this linkage was explored in a multivariate model that offered insights that are not available through the use of the kind of bivariate models used in many prior studies. The investigated markets are not linked to the extent that each market has the same importance in terms of price discovery—some markets are more important than others at particular time intervals. The individual markets do retain some of their own characteristics, as shown by the long-run forecast error decompositions, although this varies between the markets of Australia, Germany and the US.

In summary, the VAR models applied in this study helped to describe the impacts of the solar and wind prices on the integrated global electricity spot and options markets. They further assisted with making predictions and with forecasting. The analyses showed that the relationships between the four variables of interest were discernible using the times series methodology. The results of this study contribute valuable empirical evidence to energy analysts, government organisations and policymakers in terms of the GC, IRA and FEVD analyses. Moreover, the results lend support to the growth of renewable energy sources, not only in terms of energy consumption and energy production, but also in relation to renewable energy investments in Australia, Germany, the US and other regions worldwide. In addition, energy policies that support renewables are in line with medium- and long-term aims regarding the reduction of GHG emissions, such as the Kyoto Protocol target for 2020 (Maamoun, 2019; United Nations, 1998) and the zero net emissions aim for 2050 (Rogelj et al., 2015; Sokolov et al., 2015).

In terms of future research, this study only examined the impacts of the solar and wind prices on the electricity spot and options markets in Australia, Germany and the US. Future studies could examine other renewable energy price variables, such as hydropower (Guggenheim S&P Global Water Index) and uranium (MVIS Global Uranium and Nuclear Energy Index). Another potential avenue for future research concerns conducting similar studies in other regions of the world. The most obvious candidates would be other countries, such as India and China, either individually or as part of a panel study. The findings of such studies could have important policy implications, particularly if the hydropower and uranium prices were added as further variables within the VAR framework.

Moreover, while both this study and the majority of previous studies mostly used quantitative methods to gain an understanding of the influence of renewable energy as a whole, far fewer qualitative approaches have been used to study the influence of a country's solar and wind policies/regulations or, more generally, a country's view concerning the impact of green alternatives on energy pricing. In fact, no studies have truly explored the impacts of wind and solar power on the electricity spot and option markets using a qualitative methodology. Interviews with CEOs and energy delegates could provide useful information that could then be subjected to a content analysis, for example, to study the nature of any effects of wind and solar power that on the electricity spot and options volatility and long-term pricing.

REFERENCES

Alsaedi, Y.H., Tularam, G.A. (2019), The relationship between electricity consumption, peak load and GDP in Saudi Arabia: A VAR analysis. Mathematics and Computers in Simulation. DOI: 10.1016/j.matcom.2019.06.012.

Alsaedi, Y.H., Tularam, G.A., Wong, V. (2019), Application of ARIMA modelling for the forecasting of solar, wind, spot and options electricity prices: The Australian National Electricity Market. International Journal of Energy Economics and Policy, 9, 263-272.

Anderson, S. (2017), Hazelwood Power Station Closure: What Does it Mean for Electricity Bills, the Environment and the Latrobe Valley? Availablrfrom: https://www.abc.net.au/news/2017-03-30/hazelwood-power-plant-shutdown-explained/8379756. [Last accessed on 2019 Oct 24].

Asche, F., Osmundsen, P., Sandsmark, M. (2006), The UK market for natural gas, oil and electricity: Are the prices decoupled? The Energy Journal, 2, 27-40.

Astier, N., Lambin, X. (2019), Ensuring capacity adequacy in liberalised electricity markets. The Energy Journal, 40(3), 227-242.

Ata, N.K. (2018), Assessing the future of renewable energy consumption for United Kingdom, Turkey and Nigeria. Foresight and STI Governance, 12(4), 62-77.

Bansal, N., Srivastava, V., Kheraluwala, J. (2019) Renewable energy in India: Policies to reduce greenhouse gas emissions. In: Bansal, N., Srivastava, V., Kheraluwala, J., editors. Greenhouse Gas Emissions: Challenges, Technologies and Solutions. Singapore: Springer. p161-178.

Benth, F.E., Schmeck, M.D. (2014), Pricing futures and options in electricity markets. In: Ramos, S., Veiga, H., editors. The Interrelationship between Financial and Energy Markets. Berlin: Springer. p233-260.

Bernal, B., Molero, J.C., De Gracia, F.P. (2019), Impact of fossil fuel prices on electricity prices in Mexico. Journal of Economic Studies, 46(2), 356-371.

Bloomberg New Energy Finance. (2019), Clean Energy Investment Trends 2018. Available from: https://www.about.bnef.com/clean-energy-investment. [Last accessed on 2019 Oct 24].

BNEF. (2019) OpenNEM: An Open Platform for National Electricity Market Data. Available from: https://wwww.opennem.org.au/energy/nem. [Last accessed on 2019 Oct 24].

Brooks, C. (2019), Introductory Econometrics for Finance. Cambridge: Cambridge University Press.

Bunn, D.W., Gianfreda, A. (2010), Integration and shock transmissions across European electricity forward markets. Energy Economics, 32, 278-291.

Chen, S., Härdle, W.K., Cabrera, B.L. (2019), Regularization approach for network modeling of German power derivative market. Energy Economics, 83, 180-196.

Chen, W.M. (2019), The US electricity market twenty years after restructuring: A review experience in the state of Delaware. Utilities Policy, 57, 24-32.

Clean Energy Council. (2019), Clean Energy Australia Report 2018. Available from: https://www.assets.cleanenergycouncil.org.au/documents/resources/reports/clean-energy-australia/clean-energy-australia-report-2019.pdf. [Last accessed on 2019 Oct 24].

Cludius, J., Hermann, H., Matthes, F.C., Graichen, V. (2014), The merit order effect of wind and photovoltaic electricity generation in Germany 2008-2016: Estimation and distributional implications. Energy Economics, 44, 302-313.

Csereklyei, Z., Qu, S., Ancev, T. (2019), The effect of wind and solar power generation on wholesale electricity prices in Australia. Energy Policy, 131, 358-369.

de Menezes, L.M., Houllier, M.A., Tamvakis, M. (2016), Time-varying convergence in European electricity spot markets and their association with carbon and fuel prices. Energy Policy, 88, 613-627.

Energy Charts. (2019), Electricity generation. Available from: https://www.energy-charts.de/energy.htm?source=solar-wind&period=annual&year=all. [Last accessed on 2019 Oct 24].

Energy Information Administration. (2019), EIA-Annual Energy Outlook. Available from: https://www.eia.gov/outlooks/aeo. [Last accessed on 2019 Oct 24].

Ferkingstad, E., Løland, A., Wilhelmsen, M. (2011), Causal modeling and inference for electricity markets. Energy Economics, 33, 404-412.

Forrest, S., MacGill, I. (2013), Assessing the impact of wind generation on wholesale prices and generator dispatch in the Australian national electricity market. Energy Policy, 59, 120-132.

Gianfreda, A., Parisio, L., Pelagatti, M. (2016), Revisiting long-run relations in power markets with high RES penetration. Energy Policy, 94, 432-445.

Gianfreda, A., Parisio, L., Pelagatti, M. (2018), A review of balancing costs in Italy before and after RES introduction. Renewable and Sustainable Energy Reviews, 91, 549-563.

Granger, C.W. (1969), Investigating causal relations by econometric models and cross-spectral methods. Econometrica: Journal of the Econometric Society, 37, 424-438.

Hassan, O.M., Tularam, G.A. (2018), The effects of climate change on rural-urban migration in Sub-Saharan Africa (SSA) the cases of democratic republic of Congo, Kenya and Niger. In: Malcangio, D., editor. Applications in Water Systems Management and Modeling. Ch. 2. IntechOpen.

Higgs, H. (2009), Modelling price and volatility inter-relationships in the Australian wholesale spot electricity markets. Energy Economics, 31, 748-756.

Ivanov, V., Kilian, L. (2005), A practitioner's guide to lag order selection for VAR impulse response analysis. Studies in Nonlinear Dynamics and Econometrics, 9(1), 1-36.

Kang, S.B., Létourneau, P., Sala, S.X. (2019), Is it still economic to build a new coal-fired power plant in the US? A real option analysis. Applied Economics Letters, 26, 736-740.

Kaufmann, R.K., Vaid, D. (2016), Lower electricity prices and greenhouse gas emissions due to rooftop solar: Empirical results for Massachusetts. Energy Policy, 93, 345-352.

Keppler, J.H., Phan, S., Le Pen, Y. (2016), The impacts of variable renewable production and market coupling on the convergence of French and German electricity prices. The Energy Journal, 37, 343-359.

Kireyev, M.A. (2000), Comparative Macroeconomic Dynamics in the Arab World: A Panel VAR Approach. International Monetary Fund Working Paper No. 00/54. Available from: https://www.imf.org/en/Publications/WP/Issues/2016/12/30/Comparative-Macroeconomic-Dynamics-in-the-Arab-World-A-Panel-Var-Approach-3500. [Last accessed on 2019 Oct 24].

Kyritsis, E., Andersson, J., Serletis, A. (2017), Electricity prices, large-scale renewable integration, and policy implications. Energy Policy, 101, 550-560.

Lund, H., Mathiesen, B.V. (2009), Energy system analysis of 100% renewable energy systems the case of Denmark in years 2030 and 2050. Energy, 34, 524-531.

Lütkepohl, H. (2005), New Introduction to Multiple Time Series Analysis. Berlin: Springer Science and Business Media.

Maamoun, N. (2019), The kyoto protocol: Empirical evidence of a hidden success. Journal of Environmental Economics and Management, 95, 227-256.

Maryniak, P., Trück, S., Weron, R. (2019), Carbon pricing and electricity markets the case of the Australian clean energy bill. Energy Economics, 79, 45-58.

Mjelde, J.W., Bessler, D.A. (2009), Market integration among electricity markets and their major fuel source markets. Energy Economics, 31, 482-491.

Monteiro, C., Ramirez-Rosado, I.J., Fernandez-Jimenez, L.A., Conde, P. (2016), Short-term price forecasting models based on artificial neural networks for intraday sessions in the Iberian electricity market. Energies, 9(9), 721-745.

Newbery, D. (2018), The reform of network industries: Evaluating privatisation, regulation and liberalisation in the EU. Economics of Energy and Environmental Policy, 7, 145-149.

Nikkinen, J., Rothovius, T. (2019), Market specific seasonal trading behavior in NASDAQ OMX electricity options. Journal of Commodity Markets, 13, 16-29.

Park, H., Mjelde, J.W., Bessler, D.A. (2006), Price dynamics among US electricity spot markets. Energy Economics, 28, 81-101.

Paschen, M. (2016), Dynamic analysis of the German day-ahead electricity spot market. Energy Economics, 59, 118-128.

Pesaran, H.H., Shin, Y. (1998), Generalized impulse response analysis in linear multivariate models. Economics Letters, 58, 17-29.

Reboredo, J.C., Ugolini, A. (2018), The impact of energy prices on clean energy stock prices. A multivariate quantile dependence approach. Energy Economics, 76, 136-152.

Reza, R., Tularam, G.A., Li, B. (2017), An investigation into the interdependence of global water indices: A VAR analysis. Applied Economics, 49, 769-796.

Rogelj, J., Schaeffer, M., Hare, B. (2015) Timetables for Zero Emissions and 2050 Emissions Reductions: State of the Science for the ADP Agreement. Climate Analytics. Available from: http://www.climateanalytics.org/publications/2015/timetables-for-zero-emissions-and-2015-emissions-reductions. [Last accessed on 2019 Oct 24].

Sims, C.A. (1980), Macroeconomics and reality. Econometrica: Journal of the Econometric Society, 48, 1-48.

Simshauser, P., Tiernan, A. (2019), Climate change policy discontinuity and its effects on Australia's national electricity market. Australian Journal of Public Administration, 78, 17-36.

Sioshansi, F.P. (2013), Evolution of Global Electricity Markets: New Paradigms, New Challenges, New Approaches. Cambridge, MA: Academic Press.

Sokolov, A., Paltsev, S., Chen, H., Haigh, M., Prinn, R. (2015), Climate Stabilization at 2 C and "Net Zero" Emissions. AGU Fall Meeting Abstract GC43C-1212. Available from: https://www.agu.confex.com/agu/fm15/meetingapp.cgi/Paper/66532. [Last accessed on 2019 Oct 24].

United Nations. (1998), Kyoto protocol to the United Nations framework convention on climate change. Review of European Community and International Environment Law, 7, 214-217.

Weron, R. (2014), Electricity price forecasting: A review of the state-of-the-art with a look into the future. International Journal of Forecasting, 30, 1030-1081.

Wong, V.S., El Massah, S. (2018), Recent evidence on the oil price shocks on Gulf Cooperation Council stock markets. International Journal of the Economics of Business, 25, 297-312.

Woo, C.K., Horowitz, I., Moore, J., Pacheco, A. (2011), The impact of wind generation on the electricity spot-market price level and variance: The Texas experience. Energy Policy, 39, 3939-3944.

Worthington, A., Higgs, H. (2017), The impact of generation mix on Australian wholesale electricity prices. Energy Sources, Part B: Economics, Planning, and Policy, 12, 223-230.

Würzburg, K., Labandeira, X., Linares, P. (2013), Renewable generation and electricity prices: Taking stock and new evidence for Germany and Austria. Energy Economics, 40, S159-S171.

Zahedi, A. (2010), Australian renewable energy progress. Renewable and Sustainable Energy Reviews, 14, 2208-2213.