Have Competitive Electricity Markets Rewarded Flexible Gas-Powered Generation? Australia's Lessons for ASEAN

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Abstract The presence of a competitive electricity market, which allows high prices to reflect generation shortage, is often assumed to be a beneficiary factor for gas-powered generation, but the actual impact of a competitive electricity market on gas generation is yet to be examined. Using Australian daily gas and electricity data, this paper investigates whether Australia's competitive electricity markets have promoted the development of gas power generation (GPG). Considering the significant renewable energy penetration and increasing GPG in Australia and Australia's highly transparent competitive electricity market, the Australian case offers future scenarios that developing countries may face. The empirical tests fully support the hypothesis, namely GPG is negatively related to generation from VREs and positively related to electricity demand gap and electricity price. The findings suggest that ASEAN should boost gas use, continue electricity market liberalisation and regional electricity market integration.

Keywords Electricity market · Renewable · Gas power · Australia

JEL Classifications Q41 · C32

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1 Introduction

A competitive electricity market, which allows high prices to reflect generation shortage, is often assumed to be a beneficiary factor for gas-powered generation (GPG) (Devlin et al. 2017). However, the actual impact of a competitive electricity market on gas generation is yet to be examined. Natural gas is widely considered a transitional fuel during the energy transition process due to its flexibility in power generation that can mitigate volatility from variable renewable energies (VREs). Due to the relatively high costs of gas to coal, GPG is not competitive with coal-fired generation in a competitive market, except in the United States, where gas prices are low due to the shale gas revolution. However, GPG could be a cost-competitive solution to avoid the high system integration costs of a large share of VREs (Atwa and El-Saadany 2010). In the case of higher-than-usual demand for electricity or low generation from VREs, GPG will step in to fill the gap, which earns its reputation as a peak demand generator. For this flexible role, when gird scale storage is not available, the availability of GPG capacity will determine the penetration of VREs. However, due to its intermittent use induced by low generation from VREs, gas power generator needs high prices to be economically feasible. A competitive electricity market based on merit-order in dispatch could accelerate the development of VREs in theory. However, the role of the electricity market in facilitating VREs is certain as real-world evidence is mixed. For example, GPG was crowded out of the German generation mix (Hörnlein 2019).

Understanding the relationship between GPG and VREs is important as the rising VREs share worldwide prompts the question of who will provide the backup to offset the variability of VREs. While the development of storage technologies is the ultimate solution, GPG is considered an immediate and transitional solution. Much of the literature considers a functional gas market will provide the price signals for GPG. However, the relationship between GPG and VREs is complicated in that VREs could reduce the gas generation.

The Australian case provides an interesting example to investigate the role of the electricity market on the development of flexible generation capacity needed to mitigate VREs. The Australian national electricity market (NEM), which commenced operation as a wholesale spot market for electricity in December 1998, is one of the most successful electricity markets in the world. However, while VREs increased dramatically in capacity and generation, GPG is stable, and the capacity even declined between 2014 and 2020. Furthermore, two more GPG plants were being closed before 2022, and the future of the rest of the GPG plants is uncertain (Australian Energy Regulator 2021). The Morrison government proposed a gas-fired recovery to boost economic growth during the COVID-19 pandemic (Australian Government 2020). The policy assumes that Australia has abundant gas reserves, so GPG is affordable and can function as a critical enabler of the economy. However, the first project under this plan has invited many objections to the government investing in new gas (Guardian 2020). The Australian pioneer experience can inform latecomers in electricity market development, including Southeast Asian nations.

Considering the significant renewable energy penetration and increasing GPG in Australia and its highly transparent competitive electricity market in terms of historical prices and generating plant dispatch, with Australian daily gas and electricity data, this paper investigates: (i) whether GPG is negatively related to the generation from VREs, (ii) whether GPG and gas prices are positively related to electricity demand gap and electricity prices, and (iii) whether gas prices have mixed relationships with GPG.

The main contribution of this paper is threefold. Firstly, this chapter presents empirical studies on the relationship between electricity and natural gas markets in Australian NEM with daily data. Secondly, it presents an econometric analysis of the impact of renewable energy generation on GPG through actual generation instead of generation capacity. Thirdly, this chapter statistically tests the interplay between the gas and the electricity markets from multiple perspectives by using various time-series models and available daily data in different locations of Australia, considering the season effect, region effect, and endogenous effect, which provides convincing evidence to support this chapter's conclusion.

The paper proceeds as follows. After the introduction, Sect. 2 discusses the Australian NEM and the development of VREs and GPG. There researchers' hypotheses are proposed based on NEM and literature review. Section 3 reports the data and methodology. The empirical results are presented in Sect. 4 followed by implications for ASEAN and other latecomers in the electricity market. The last section concludes the paper.

2 Background and Research Hypotheses

2.1 The Australian National Electricity Market (NEM) in Transition

NEM started operation in December 1998 and spans Australia's eastern and south-eastern coasts, including six interconnected states and territories and five price regions: New South Wales (NSW) (including the Australian Capital Territory), Queensland, Victoria, South Australia, and Tasmania.[1] NEM is one of the world's largest interconnected electricity systems, having around 40,000 km of transmission lines and cables, delivering around 80% of Australia's electricity consumption, and supplying 10.2 million customers (DISER 2021). Around 30 retailers and over 100 generation companies are in the NEM wholesale market. There are also eight frequency control ancillary services spot market prices, with electricity production and frequency control services co-optimised across five imperfectly interconnected states or regions (Table 1).

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[1] Due to the distance between networks, Western Australia and the Northern Territory are not connected to NEM. They have their own electricity systems and separate regulatory arrangements.

Table 1 National electricity market, January 2021

Participating jurisdictions	OLD, NSW, VIC, SA, TAS, ACT
NEM regions	OLD, NSW, VIC, SA, TAS,
NEM installed capacity (including rooftop solar)	67,046 MW
Number of large generating units	295
Number of customers	10.2 million
NEM turnover 2020	$10.9 billion
Total electricity consumption 2020	190.1 TWh
National maximum demand 2020	35,043 MW

Source Australian Energy Regulator (2021)

NEM is a wholesale market where exchange between electricity producers and electricity consumers is facilitated through an electricity pool, a set of procedures that the Australian Energy Market Operator (AEMO) manages according to laws, regulations, and rules rather than a physical location. NEM is made possible by sophisticated information technology systems that balance supply with demand, maintain reserve requirements, determine dispatch and the spot price, and facilitate the financial settlement of the physical market (AEMO 2010).

NEM has a transparent and balanced regulatory framework, including various key institutions (DISER 2021). The Australian Energy Market Commission (AEMC) develops market operation rules, and the Australian Energy Regulator (AER) enforces the rules and judgments on the regulatory proposals of monopoly network operators. AEMO handles day-to-day operations of the electricity and gas markets. The Energy Security Board (ESB) was established to monitor NEM's system performance, risks, improvement opportunities, and affordability to safeguard NEM's health. The ESB also coordinates the implementation of the reform blueprint produced by Australia's chief scientist. The Australian Competition and Consumer Commission informs the Australian government on long-term energy policies that may be changed due to changes in electricity generation, emerging technologies, such as solar batteries, and shifting consumer preferences. The policies will further promote NEM's modernisation.

2.2 Energy Transition in Australia's Electricity Generation

Energy transition has progressed well in Australia's electricity market, summarised from two aspects: capacity and electricity generation by fuel type. Figure 1 shows that the generation capacity for black and brown coal has declined in the past 2
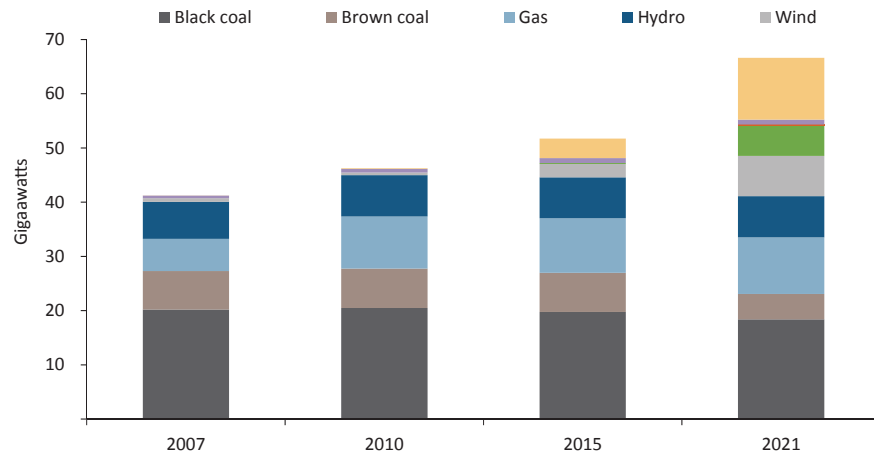
Fig. 1 Generation capacity, by generation technology. *Source* Australian Energy Regulator (2021)

decades, accounting for 66.2% in 2007 and 34.6% in 2021. Meanwhile, wind and solar generation capacity has dramatically increased after 2015. Notably, solar PV (including solar farms and rooftop solar) was the second-largest generation technology in Australia in 2021. The total VREs generation capacity is the largest amongst all fuels, 36.9%.

Moreover, a close examination of the change in generation capacity can better demonstrate the transition in the power generation sector. According to Fig. 2, there has been no new investment in coal-fired generation in Australia since 2012, and almost 4 gigawatts (GW) of coal-fired generation has left the market since 2012. On the contrary, around 12.5 GW of large-scale wind and solar capacity and 8.5 GW of
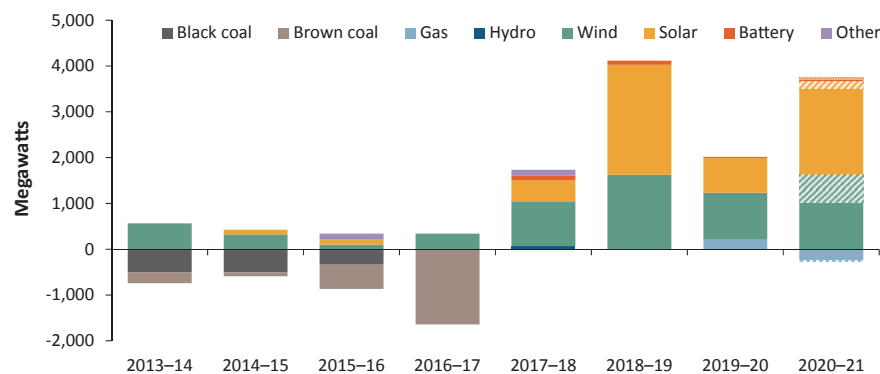

Fig. 2 Entry and exit of generation capacity in NEM by generation technology. *Note* Capacity includes scheduled and semi-scheduled generation but not non-scheduled or rooftop PV capacity. 2020–2021 data are on 31 March 2021. Investment and closures expected between 1 April and 30 June 2021 are shown as shaded components. *Source* Australian Energy Regulator (2021)
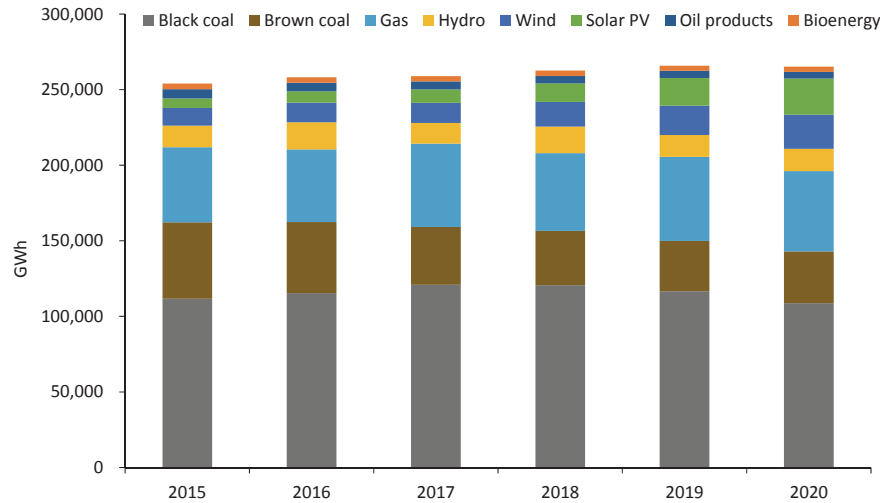
Fig. 3 Australian electricity generation by fuel type. *Source* Department of Industry Innovation and Science (2021)

rooftop solar PV began operating over this same period and significantly increased dramatically from 2017.

Regarding electricity generation by fuel type in Australia, the proportion of generation from coal declined from 63.9% in 2015 to 53.9% in 2020. Meanwhile, the proportion of generation from VREs increased from 14.1 to 24.4%. Notably, solar power grew by 30.3% in 2020 and overtook wind to be the largest contributor to VREs, with a 36.9% share of renewable generation and 9.5% of total electricity generation in Australia (Fig. 3).

As for the generation output by fuel source in NEM, the proportion of generation output from VREs has reached 27.3%, of which the proportion of wind generation output is 13.9% (Table 2).

2.3 Development of GPG and VREs

GPGs typically operate as 'flexible' or 'peaking' plants in Australia because gas is a relatively expensive fuel for electricity generation. Gas generation will be operated when electricity demand and prices are highest; it also tends to be seasonal. Furthermore, it is strongly affected by the increasing renewable generation and withdrawal of coal-fired generators.

GPG plays an increasingly crucial role in managing the variability of output of weather-dependent renewable generations. However, GPG capacity has not been developed along with the VREs. While VRE generation capacity increased from 674 MW in 2007 to 24,614 MW in 2021, GPG capacity only increased from

Table 2 Generation in NEM by fuel source (as of 30 September 2021)

Fuel	NEM capacity (% of total generation)	NEM output (% of total generation)
Black coal	32.0	49.2
Brown coal	8.4	16.7
Gas	17.1	6.4
Hydro	14.6	9.3
Wind	14.7	13.9
Liquid	1.3	0.1
Grid solar	9.9	3.9
Battery	0.6	0.1
Other	1.4	0.4

Source Australian Energy Regulator (2021)

5,946 MW to 10,436 MW at the same time. Moreover, GPG capacity declined between 2014 and 2021 (Fig. 4), despite a small new investment in gas generation in 2019. Two GPG plants were also scheduled to retire in 2020–2022. The future of other plants is speculated to be in danger, too.

The gas power generation is also not in parallel with VRE development. For example, while VRE generation increased 126-fold from 260 GWh in 2000–2001 to 32,778.8 GWh in 2018–2019, the GPG only increased threefold from 17,271 to 52,387 GWh in the same period. Particularly, when VRE generation increased 430% in 2010–2019, the GPG only increased 7% (Fig. 5).
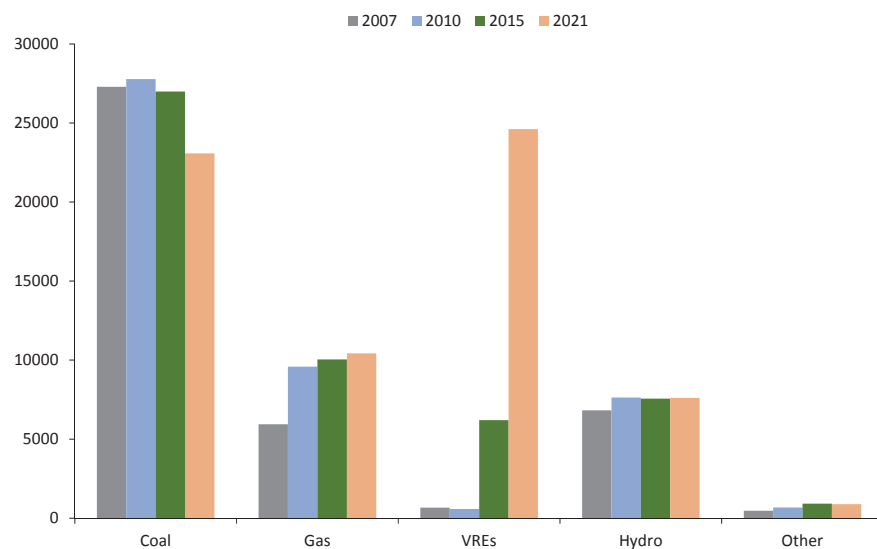
Fig. 4 Generation capacity by technology (MW). *Source* Australian Energy Regulator (2021)
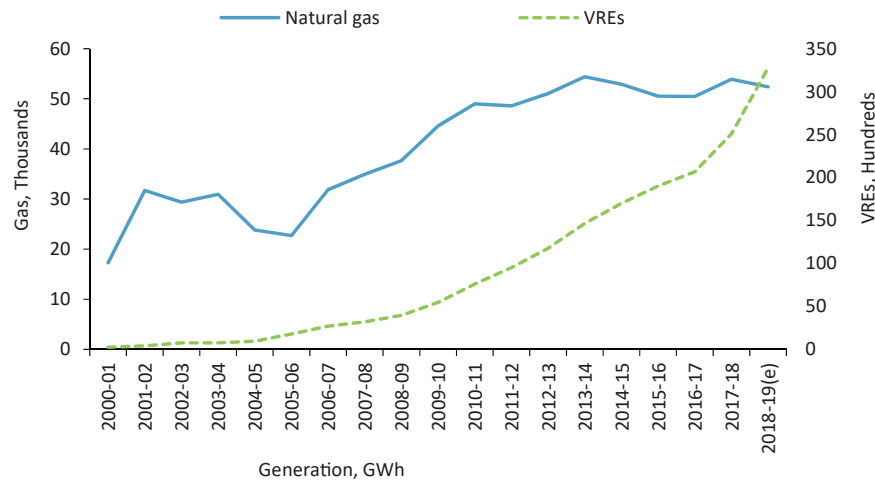
Fig. 5 Generation in the Australian national electricity market. *Sources* Department of Industry Innovation and Science (2021)

The lack of parallel development between GPG and VREs could be due to a low frequency of high electricity prices and a high frequency of high gas prices. Due to the large share of renewables in the generation mix, the capability of coal and gas plants to set high dispatch prices declines (AER 2020). The number of intervals when the spot electricity price is above $300 per MWh in NEM (Fig. 6) may impair the profitability of gas plants that often rely on selling cap contracts to customers that wish to insure against high prices. This low frequency of high electricity prices is in contrast with the significantly increased gas prices from 2015 to 2018 when Queensland's liquefied natural gas (LNG) plants purchased gas supplies from the domestic market to meet export obligations (Grafton et al. 2018). Gas prices were volatile in 2017 due to the
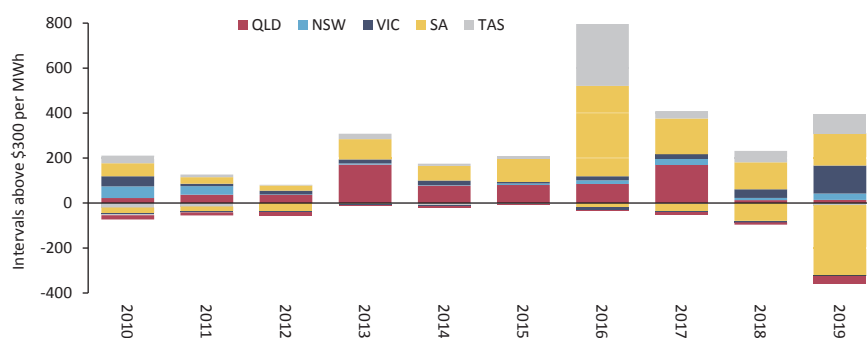

Fig. 6 Prices above $300 per MWh and below—$100 per MWh (number of intervals). NSW = New South Wales, QLD = Queensland, SA = South Africa, TAS = Tasmania, VIC = Victoria. *Source* Australian Energy Regulator (2021)

LNG export and large brown coal plant closures (Hazelwood and Northern). These events resulted in high electricity prices across NEM despite electricity demand remaining flat. Higher fuel costs further worsened the economic viability of the GPG during this period. Recent dramatic falls in NEM electricity prices followed the domestic gas market, which has followed the world LNG markets. Given that the NEM market structure and demand have not changed much since 2017, it is hard to see how it could be suggested that the level of generation competition has had any material impact on electricity price outcomes—either high or low.

2.4 Regional Generation Mix

The generation mix has significant heterogeneity across the states or territories in NEM. From the regional distribution of the generation capacity, coal is the dominant generation source in NSW and Queensland, while gas and VREs dominate South Australia, and hydroelectricity dominates Tasmania (Fig. 7). Moreover, wind generation capacity in Australia's NEM is located mainly in Victoria, South Australia, and NSW. Solar generation capacity is situated primarily in NSW and Queensland. Meanwhile, GPG capacity is located mainly in Queensland, South Australia, Victoria, and NSW. Each of these regions also has short-term gas trading hubs. Australian domestic wholesale gas price market hubs are found in Adelaide, Sydney, Brisbane, and Victoria's Declared Wholesale Gas Market (DWGM) (Grafton et al. 2018).

As for the electricity generation in 2020, coal was still the dominant generation source in NSW, Victoria, and Queensland, while VREs and hydrogen dominate South Australia and Tasmania (Fig. 8). In terms of emissions, South Australia and Tasmania have done well.
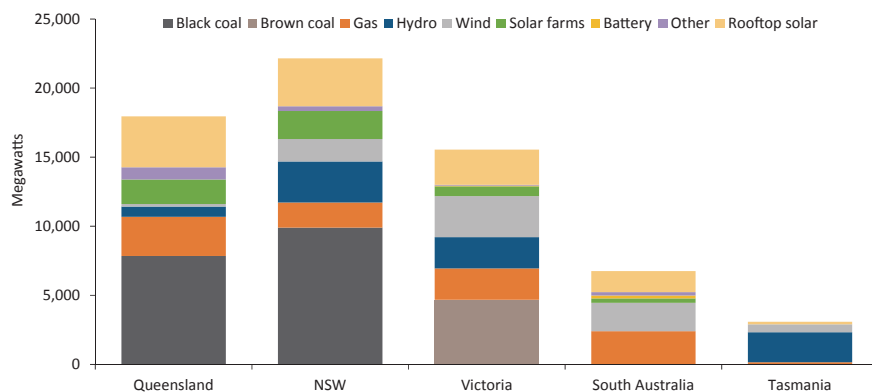

Fig. 7 Generation capacity in the national electricity market by region and fuel course in 2020. *Note* Generation capacity on 1 January 2021. Other dispatch includes biomass, waste gas, and liquid fuels. *Source* Australian Energy Regulator (2021)
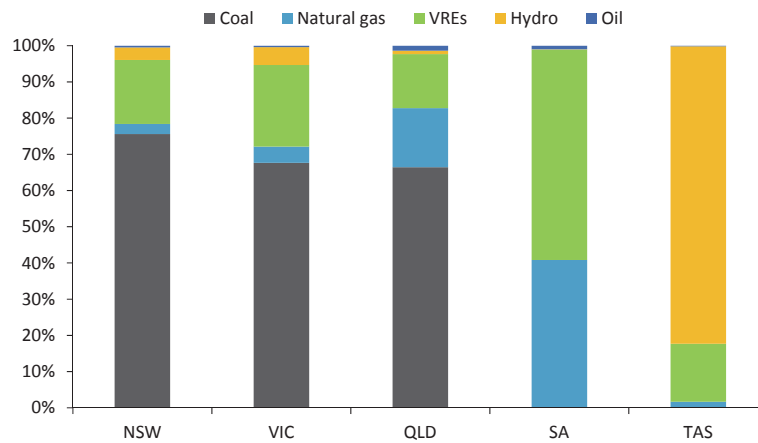
Fig. 8 Australian electricity generation mix by state, 2020. *Source* Department of Industry Innovation and Science (2021)

The proportion of GPG in South Australia is still the largest, at 56.6% and 55.0% in 2007 and 2017, respectively. That declined to 40.9% in 2020, causing VRE generation to increase sharply (Figs. 9 and 10). On the other hand, the proportion of GPG in Queensland climbed to 22.4% in 2014, then decreased to 9.6% in 2020. The proportion is not high in other regions, but it has been decreasing in recent years.

Moreover, each state in Australia will further increase VRE investment (Fig. 11). For example, Queensland and NSW will invest more in solar generation. NSW, Victoria, and South Australia will invest more in wind generation, while the GPG investments of states are very small.
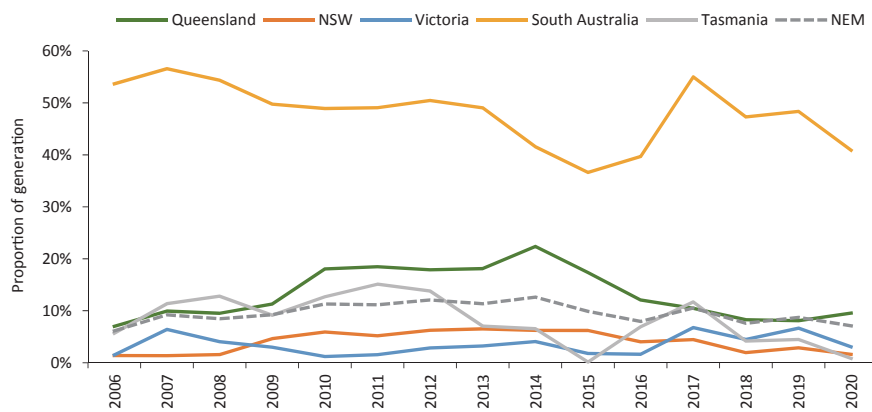
Fig. 9 The proportion of gas-powered generation. *Source* Australian Energy Regulator (2021)
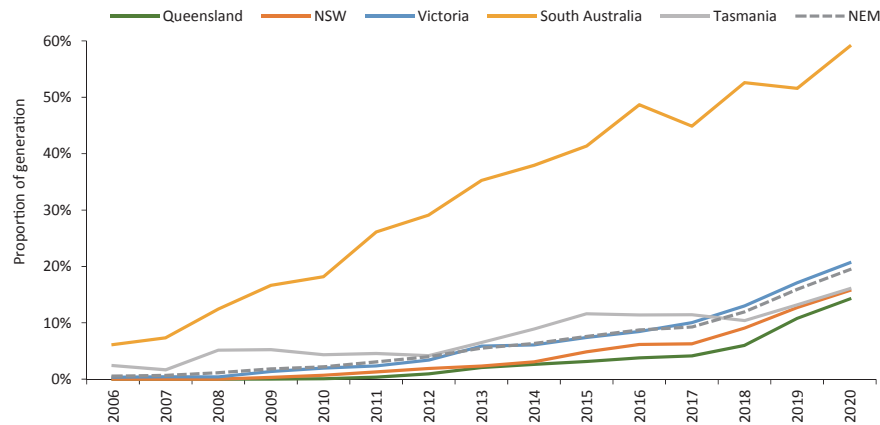
Fig. 10 The proportion of VRE generation. *Source* Australian Energy Regulator (2021) AER;
AEMO (data)
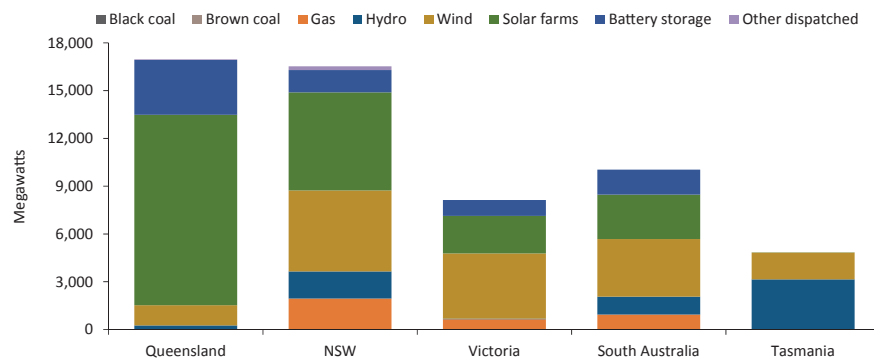
Fig. 11 Announced generation proposals, January 2021. *Source* Australian Energy Regulator
(2021)

2.5 Gas Demand

The gas demand for GPG was above 220 petajoules (PJ) before 2014 and then
declined to 116 PJ in 2020 with the increase of VERs (Fig. 12).

As for each region, the gas demand for GPG shows obvious seasonal fluctuations.
For example, there was a significant decline from 2014 in Queensland and from 2017
in other regions (Fig. 13).
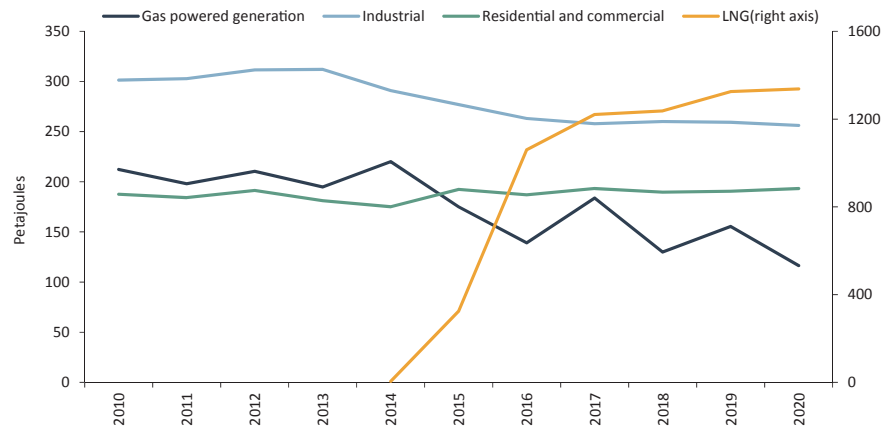
Fig. 12 Eastern Australian gas demand. *Source* (AEMO 2021)
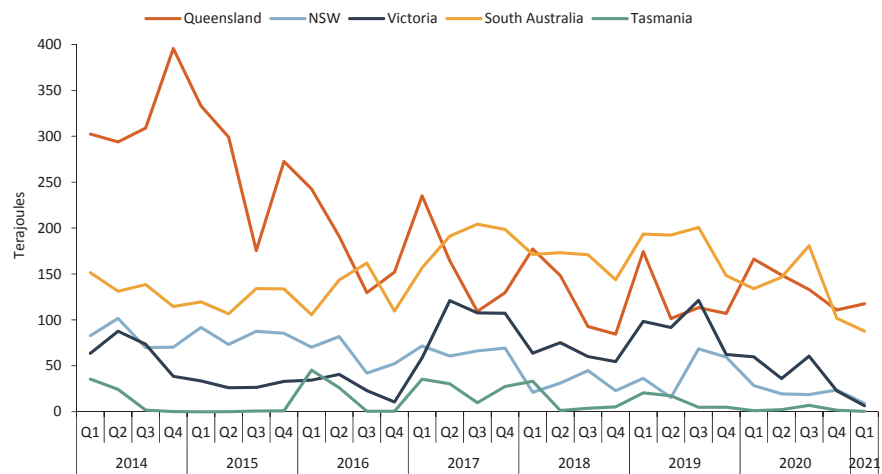
Fig. 13 Quarterly gas demand for gas-powered generation (average Tj/day). *Source* Australian Energy Regulator (2021)

2.6 The Electricity and Gas Price

The trend of electricity prices in various regions is very similar, showing obvious fluctuations and an upward trend (Fig. 14). The peaks appear in 2002, 2005, 2007 (2008 in Victoria), 2014, and 2017. The electricity prices of Victoria and South Australia reached the highest in 2019 in this period, but the electricity prices in each region dropped sharply in 2020.

The trend of gas prices in various regions is more similar, showing an inverted 'U' (Fig. 15). Moreover, the trend of gas prices is like that of electricity prices in the
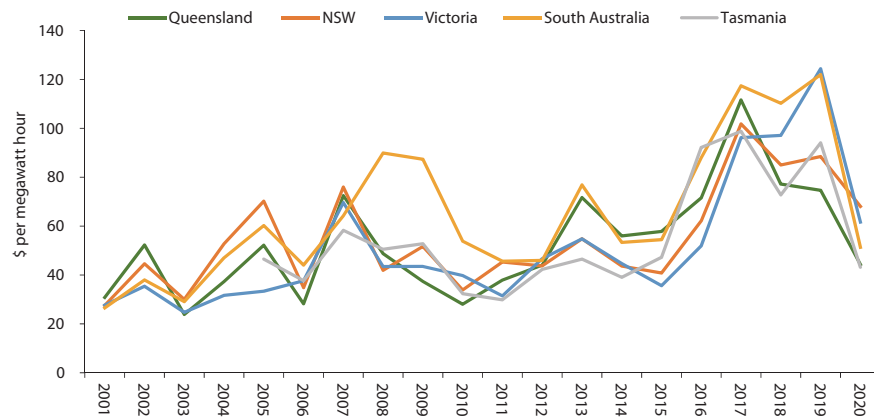
Fig. 14 Wholesale electricity prices. *Note* Volume weighted annual averages. *Source* Australian Energy Regulator (2021)
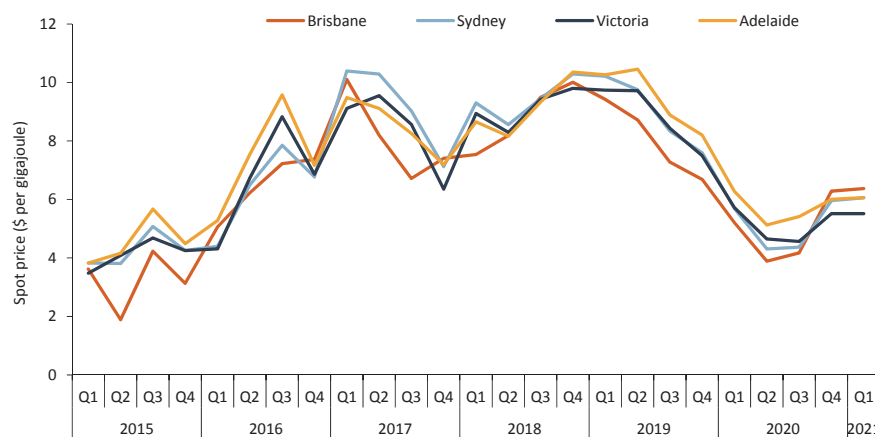
Fig. 15 Eastern Australia gas market prices. *Note* Adelaide, Brisbane, and Sydney prices are ex ante. The Victorian price is the 6 a.m. schedule price. *Source* Australian Energy Regulator (2021)

period after 2015. The peaks appear in Q1 of 2017 and Q1 of 2019, respectively, and there is a clear trough in Q2 of 2020 (Fig. 15).

2.7 Research Hypothesis

A functional electricity market will shape the relationship between the power market with high penetration of renewable energy and gas generation. Due to its capabilities of high ramp rates, quick start-ups, and relatively low emissions, the GPG provides

a lower, although not zero, emission solution to the intermittence of VREs (Heinen et al. 2017). However, whether the power market with high penetrations of renewable energy can facilitate the GPG will depend on market design, which needs to adequately reward the flexibility that, in most cases, is provided by the GPG (Devlin et al. 2017). In the Australian context, gas has been found to have a competitive role against coal, while facilitating the development of renewables (Guidolin and Alpcan 2019).

Nevertheless, the GPG is likely to be affected by VRE generation in the electricity generation partly because the GPG is functional as a backup for the VREs (Qadrdan et al. 2010). Therefore, we have the first hypothesis:

Hypothesis 1: The GPG is negatively related to VRE generation.

An increasing share of GPG results in a stronger interconnection between gas and electricity networks. The GPG is related to the electricity demand, especially the peak demand (Chen et al. 2018). Moreover, high demand tends to be associated with higher wholesale energy prices. Thus, a positive correlation exists between the wholesale spot electricity price and GPG dispatch. That leads to our second hypothesis.

Hypothesis 2: The GPG is positively related to the electricity demand gap and electricity prices.

Higher spot gas prices usually imply higher electricity prices, and this effect is amplified at higher prices due to the convexity of the bid-supply curve (Poyrazoglu and Poyrazoglu 2019). Therefore, we have the third hypothesis.

Hypothesis 3: Spot gas prices are positively related to the electricity demand gap and electricity prices.

Gas price could affect the adequacy of natural gas supply and the long-term expansion planning of electricity generation. But, on the contrary, the gas spot prices are reflected as the costs for GPG, so that gas prices will be passed through by the marginal GPG generator to the electricity price (Bolinger et al. 2006; Csereklyei et al. 2019). Therefore, we have the fourth hypothesis.

Hypothesis 4: Spot gas prices have mixed relationships with the GPG.

3 Data and Methodology

3.1 Data and Sources

Data used in this paper include electricity generation by fuel type, daily spot electricity prices, electricity demand, and daily gas prices in four regions (NSW, Victoria, Queensland, and South Australia).[2] All data are sourced from AEMO.

(1) The electricity generation dispatch data includes all units AEMO captures, namely, scheduled, semi-scheduled, and non-scheduled units in NEM, which are a 5 min dispatch interval by unit (DUID). We match the electricity generation data with the region and fuel source information for each DUID and then aggregate the data by the level of date*region *fuel source,[3] and the data spans from 1 January 2011 to 28 April 2021. The Declared Wholesale Gas Market (DWGM) also provides the daily data of GPG demand in Victoria.

(2) The electricity price data and electricity demand data date back to the start of NEM, 13 December 1998 to 28 April 2021.

(3) The spot gas prices of NSW, Queensland, and South Australia are from the short-term trading market (STTM), which includes the date, region, ex ante market price, and provisional market price, and the period is from 1 September 2010, when the STTMs started operation, to 28 April 2021. The spot gas prices data of Victoria are from the DWGM. The data period is from 1 February 2007 to 28 April 2021. Unlike the STTM, the DWGM has multiple trading prices per day. Thus, we average those prices to produce the daily prices.

3.2 Methodology

In this chapter, we use different methods to test the four hypotheses considering the relationship of variables.

To test hypotheses 1 and 2, we set up the OLS regression model for each region and the panel model for all regions as Eqs. (1) and (2).

$$
\ln gpg_t = \beta_0 + \beta_1 \ln Wind_t + \beta_2 \ln Solar_t + \beta_3 \ln ed_t + \beta_4 \ln pe_t \\
+ \beta_5 \ln gasp_t + Year_{dummy} + Season_{dummy} + \varepsilon_t
\tag{1}
$$

$$
\ln gpg_{it} = \beta_0 + \beta_1 \ln Wind_{it} + \beta_2 \ln Solar_{it} + \beta_3 \ln ed_{it} + \beta_4 \ln pe_{it} \\
+ \beta_5 \ln gasp_{it} + Year_{dummy} + Season_{dummy} + \mu_i + v_t + \varepsilon_{it}
\tag{2}
$$

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[2] The other two jurisdictions were not included because the Australian Capital Territory is a part of the NSW electricity market while the proportion of the GPG in Tasmania is very small.

[3] The fuel sources include black coal, brown coal, gas, wind, hydro, solar, biomass, battery, and liquid fuel.

where t is the time and i is the region. gpg is the daily GPG; $Wind$ and $Solar$ are the daily power generation from wind and solar, respectively; ed is the daily electricity demand gap[4]; pe is the daily spot electricity price; and $gasp$ is the daily gas price. All data in the models in this paper is in logarithmic form. $Year_{dummy}$ and $Season_{dummy}$ are the dummy variables of year and season, μ_i is the region fixed effect, and v_t is the time fixed effect. β_1 and β_2 are expected to be negative, while β_3 and β_4 are positive.

In hypothesis 3, for testing the relationship between daily gas price and electricity demand gap, we set the OLS regression model for each region and panel model for all regions, as Eqs. (3) and (4).

$$\ln gasp_t = \beta_0 + \beta_1 \ln ed_t + Year_{dummy} + Season_{dummy} + \varepsilon_t \qquad (3)$$

$$\ln gasp_{it} = \beta_0 + \beta_1 \ln ed_{it} + Year_{dummy} + Season_{dummy} + \mu_i + v_t + \varepsilon_{it} \qquad (4)$$

β_1 is expected to be positive.

Furthermore, considering the endogenous and possible causal relationship between the daily gas and electricity prices, we firstly set up VAR models for each region as Eqs. (5) and (6) and then conducted the Granger causality test.

$$\ln gpsp_t = \beta_{10} + \sum_{k}^{p} \beta_{11k} \ln gpsp_{t-k} + \sum_{k}^{p} \beta_{12k} \ln pe_{t-k} + \varepsilon_{1t} \qquad (5)$$

$$\ln pe_t = \beta_{20} + \sum_{k}^{p} \beta_{21k} \ln pe_{t-k} + \sum_{i}^{p} \beta_{22k} \ln gpsp_{t-k} + \varepsilon_{2t} \qquad (6)$$

where $\ln gpsp_{t-k}$ is the lag of daily gas generation price, and $\ln pe_{t-k}$ is the lag of spot electricity price. β_{11}, β_{12}, β_{21}, and β_{22} are expected to be positive.

To test hypothesis 4 on the mixed relationships between gas prices and the GPG, we set up VAR models as Eqs. (7) and (8) for each region and then conducted the Granger causality test.

$$\ln gasp_t = \beta_{20} + \sum_{k}^{p} \beta_{21k} \ln gasp_{t-k} + \sum_{i}^{p} \beta_{22k} \ln gpg_{t-k} + \varepsilon_{2t} \qquad (7)$$

$$\ln gpg_t = \beta_{10} + \sum_{k}^{p} \beta_{11k} \ln gpg_{t-k} \sum_{k}^{p} \beta_{12k} \ln gasp_{t-k} + \varepsilon_{1t} \qquad (8)$$

where $\ln gasp_{t-k}$ is the lag of spot gas price, and $\ln gpg_{t-k}$ is the lag of daily GPG.

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[4] The daily electricity demand gap is the difference between the potential electricity demand and the real electricity demand, which can be estimated by the HP filter method.

In addition, as AEMO provides the data of GPG demand for Victoria, which is regarded as a proxy variable of GPG, we set a robustness test for hypotheses 1 and 2 with GPG demand data in Victoria to strengthen the conclusions of this paper.

4 Empirical Results

4.1 Unit Root Test for Time Series

Firstly, we conduct the unit root tests for time series, and the results are shown in Table 3. The p value of each time series is less than 0.01, which means each series is stationary and can set up regression models directly with them.

4.2 Natural gas's Flexibility Role in the Power System

The first empirical question is whether the GPG has been functioning as a flexible and dispatchable power source in the national market. This flexibility role can be tested through two relationships: (i) GPG and the wind or solar power dispatch for GPG's backup role to VREs (hypothesis 1), and (ii) GPG and the total electricity demand for GPG's peak generator role (hypothesis 2). In each case, the dependent variable is GPG dispatch, and the core explanatory variable is wind generation and

Table 3 Unit root test results

Variables	NSW	OLD	SA	VIC	Panel
Ln (GPG dispatch)	−22.845 (0.000)	−13.748 (0.000)	−24.124 (0.000)	−28.678 (0.000)	−56.213 (0.000)
Ln (GPG demand)				−34.575 (0.000)	
Ln (wind generation)	−24.841 (0.000)	−10.068 (0.000)	−37.749 (0.000)	−31.602 (0.000)	−65.547 (0.000)
Ln (solar generation)	−9.185 (0.000)	−10.726 (0.000)	−10.745 (0.000)	−9.943 (0.000)	−34.714 (0.000)
Ln (gas price)	−13.727 (0.000)	−14.181 (0.000)	−8.214 (0.000)	−12.416 (0.000)	−24.614 (0.000)
Ln (electricity price)	−20.780 (0.000)	−27.023 (0.000)	−32.592 (0.000)	−22.121 (0.000)	−69.594 (0.000)
HP_Ln (electricity demand gap)	−22.988 (0.000)	−19.933 (0.000)	−26.299 (0.000)	−28.323 (0.000)	−51.112 (0.000)

Note In parentheses is the p value corresponding to the statistical value
Source Authors' calculations

Table 4 Testing natural gas's flexibility role in power system (for panel data)

Dependent variable	GPG dispatch						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Wind generation	−0.330***				−0.295***	−0.221***	−0.079**
	(0.016)				(0.031)	(0.030)	−0.031
Solar generation		0.019			−0.225***	−0.089**	−0.113***
		(0.028)			(0.044)	(0. 043)	−0.044
Electricity demand gap			3.872***			4.507***	3.184***
			(0.100)			(0.205)	(0.237)
Electricity price				1.088***			1.085***
				(0.030)			(0.068)
Gas price							−0.317***
							(0.116)
Constant	11.049***	9.337***	8.726***	5.199***	14.154***	12.672***	8.227***
	(0.137)	(0.210)	(0.039)	(0.107)	(0.392)	(0.382)	(0.485)
Year_dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Season_dummy	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.059	0.109	0.119	0.124	0.068	0.09	0.085
N	12,217	7,264	15,008	14,612	5,300	5,300	5,112

Note ***, **, * are statistically significant at the 1%, 5%, 10% level
Source Authors' calculations

solar generation, electricity demand gap, respectively. Table 4 shows the empirical results for panel data, and Table 5 shows the results for the regions.

Firstly, the coefficient of wind generation is negative and significant at the 1% level for the panel data, as shown in columns (1), (5)–(7) of Table 4. And as shown in Table 5, the coefficient of wind generation is also significantly negative in NSW, South Australia, and Victoria, but not significant in Queensland. Four states rely on GPG differently. In NSW, South Australia, and Victoria, GPG was squeezed due to lower grid demand and higher wind and solar output. However, the main reason for the slumping GPG in Queensland is the increasing gas fuel cost due to the start of Queensland's LNG industry rather than the wind generation.

Moreover, the wind generation proportion in Queensland is the lowest in NEM. Thus, the negative effect of wind on GPG is not significant in Queensland. In addition, the coefficient of the solar generation is negative and significant at the 1% level for panel data in columns (5)–(7) of Table 4. And the coefficient of solar generation is also significantly negative in NSW, Queensland, and Victoria when the dependent variable is GPG dispatch but not significant in Victoria when the dependent variable is GPG demand. More particularly, the coefficient is positive and significant at the 1% level in South Australia. The inconsistent coefficients of solar generation may be related to its scale. Compared to the GPG, the scale of solar generation is still small in some regions and does not have enough substitution effect on the GPG.

Table 5 Testing natural gas's flexibility role in power system (for regional data)

Dependent variable	GPG dispatch				GPG demand
	NSW	QLD	SA	VIC	VIC
	(1)	(2)	(3)	(4)	(5)
Wind generation	−0.136***	−0.019	−0.240***	−0.221***	−0.235**
	(0.065)	(0.014)	(0.013)	(0.060)	(0.116)
Solar generation	−0.362***	−0.129***	0.024**	−0.146**	−0.106
	(0.123)	(0.032)	(0.011)	(0.068)	(0.134)
Electricity demand gap	5.848***	2.880***	1.172***	3.367***	2.033**
	(0.565)	(0.169)	(0.054)	(0.478)	(0.924)
Electricity price	3.348***	0.193***	0.152***	1.522***	2.491***
	(0.202)	(0.033)	(0.016)	(0.132)	(0.220)
Gas price	−1.361***	−0.584***	0.364***	0.186	0.52
	(0.198)	(0.053)	(0.053)	(0.300)	(0.574)
Constant	1.806	10.899***	10.224***	3.622***	−10.012***
	(1.198)	(0.337)	(0.201)	(1.101)	(2.102)
Year_dummy	Yes	Yes	Yes	Yes	Yes
Season_dummy	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.433	0.566	0.748	0.443	0.366
N	2,157	974	971	1010	1,046

Note ***, **, * are statistically significant at the 1%, 5%, 10% level
Source Authors' calculations

Especially in South Australia, the proportion of GPG is the highest, and the scale of solar generation is the lowest.

On the average effect of VREs on the GPG, when the wind and solar generation increases by 1%, the GPG will decrease by an average of 0.079% and 0.113%, as in column (7) of Table 4. The negative effect of wind generation on the GPG is the largest in South Australia and is the smallest in Queensland. The negative effect of solar generation on the GPG is the largest in NSW and is the smallest in Queensland. But in South Australia, the relationship is positive. The GPG increases in South Australia may mainly link to the demand gaps due to the closure of coal power stations. Also, South Australia relies on the GPG more than other states. Thus, even though the solar generation is growing, the GPG also increases to meet the demand gaps.

The significantly negative coefficients of wind and solar generation in most models provide sufficient support for hypothesis 1, namely, the GPG is negatively related to the generation from VREs.

Secondly, the coefficients of electricity demand gap are positive and significant at the 1% level for the panel data and all regions (Tables 4 and 5). And when the electricity demand gap increases by 1%, the GPG will increase by an average of 3.184%. The positive effect is the largest in NSW and is the smallest in South Australia. The

significantly positive coefficients support hypothesis 2, namely, the GPG is positively related to the electricity demand gap.

4.3 GPG's Response to Market Price Signals

In a market setting, price signals reflect the gaps between supply and demand. Therefore, this empirical test will check how much GPG will respond to electricity prices. As in the previous case, there are estimations in panel data models (Table 4) and a separate estimation for each regional electricity market (Table 5).

Columns (4) and (7) of Tables 4 and 5 show that the coefficients of electricity prices are positive and significant at the 1% level for the panel data and all regions. And when the electricity price increases by 1%, the GPG increases by an average of 1.085%. The positive effect is the largest in NSW and is the smallest in South Australia, which is the same as the effect of electricity demand gap. In 2020, the GPG fell in NSW mainly due to low electricity prices. However, in South Australia, the reduced generation coincided with the closure of two units at gas-powered plants, which may have resulted in the smallest positive effect of electricity price on the GPG. The significantly positive effect of electricity prices on the GPG also supports hypothesis 2, namely, the GPG is positively related to electricity prices.

4.4 Interrelationship Between Gas and Electricity Prices

The active role of the GPG in the power market will form a close relationship between the natural gas market and the electricity markets. These will have two sub-hypotheses.

4.4.1 Spot Gas Prices Will Positively Respond to Electricity Prices

We construct a VAR model and Granger causality test to explore the relationship between gas prices and electricity prices for the hypothesis. The results are shown in Tables 6 and 7.

It can be seen that electricity prices of a day lag period have a positive impact on the gas prices, and gas prices of a day and 2 days lag period also positively impact on the electricity prices. In addition, the gas price does Granger-cause electricity price, and electricity price also does Granger-cause gas price in all four regions.

Table 6 The relationship between gas and electricity prices

	NSW	QLD	SA	VIC	Panel (FE)
	(1)	(2)	(3)	(4)	(5)
Dependent variable: Gas price					
L1. Gas price	0.622***	0.660***	0.753***	0.712***	0.671***
	(0.016)	(0.017)	(0.016)	(0.016)	(0.008)
L2. Gas price	0.241***	0.214***	0.208***	0.208***	0.227***
	(0.016)	(0.017)	(0.016)	(0.016)	(0.008)
L1. Electricity price	0.096***	0.113***	0.021***	0.027***	0.055***
	(0.015)	(0.017)	(0.003)	(0.009)	(0.005)
L2. Electricity price	0.011	−0.018	−0.009***	0.004	0.000***
	(0.014)	(0.016)	(0.003)	(0.009)	(0.005)
Constant	−0.194***	−0.173***	0.015	0.009	−0.050***
	(0.033)	(0.048)	(0.010)	(0.019)	(0.014)
Dependent variable: Electricity price					
L1. Electricity price	0.607***	0.507***	0.378***	0.628***	0.511***
	(0.014)	(0.016)	(0.016)	(0.016)	(0.008)
L2. Electricity price	0.145***	0.136***	0.089***	0.065***	0.129***
	(0.014)	(0.015)	(0.016)	(0.015)	(0.008)
L1. Gas price	0.103***	0.091***	0.454***	0.182***	0.145***
	(0.015)	(0.015)	(0.081)	(0.028)	(0.013)
L2. Gas price	0.042***	0.049***	−0.016	0.054*	0.064***
	(0.015)	(0.015)	(0.080)	(0.028)	(0.012)
Constant	0.729***	1.174***	1.334***	0.796***	1.055***
	(0.031)	(0.044)	(0.050)	(0.034)	(0.021)
N	3,713	3,352	3,452	3,665	14,182

Note ***, **, * are statistically significant at the 1%, 5%, 10% level
Source Authors' calculations

4.4.2 Spot Gas Prices Are Positively Related to Electricity Demand

We construct the OLS model and panel fixed model to test the relationship between gas prices and electricity demand, and the results are shown in Table 8. It can be seen that the coefficients of electricity demand are positive and significant at the 1% level for all models. This means that the electricity demand is positively related to gas prices; when electricity demand increases by 1%, gas prices increase by an average of 0.463%. The positive impact of electricity demand on gas prices is the largest in Queensland and the smallest in South Australia.

Hence, the results of Tables 6, 7, 8 support hypothesis 3 that spot gas prices are positively related to electricity prices and electricity demand.

Table 7 Granger causality Wald tests for gas and electricity prices

		H0: Electricity price does not granger-cause gas price	H0: Gas price does not granger-cause electricity price
NSW	chi2	103.560	245.860
	P	0.000	0.000
QLD	chi2	59.661	239.080
	P	0.000	0.000
SA	chi2	41.200	316.690
	P	0.000	0.000
VIC	chi2	21.602	274.390
	P	0.000	0.000

NSW = New South Wales, QLD = Queensland, SA = South Australia, VIC = Victoria
Note In parentheses is the p value corresponding to the statistical value
Source Authors' calculations

Table 8 The relationship between gas prices and electricity demand

Dependent variable	Gas Price				
	NSW	QLD	SA	VIC	Panel (FE)
	(1)	(2)	(3)	(4)	(5)
Electricity demand	0.733^{***} (0.056)	0.781^{***} (0.134)	0.288^{***} (0.019)	0.475^{***} (0.038)	0.463^{***} (0.025)
Constant	0.983^{***} (0.017)	1.190^{***} (0.087)	1.231^{***} (0.010)	0.991^{***} (0.014)	1.072^{***} (0.011)
Year_dummy	Yes	Yes	Yes	Yes	Yes
Season_dummy	Yes	Yes	Yes	Yes	Yes
Adj R^2	0.681	0.523	0.810	0.747	0.594
N	3,764	3,426	37,548	3,761	14,705

Note ***, **, * are statistically significant at the 1%, 5%, 10% level
Source Authors' calculations

4.5 Interrelation Between the GPG and Gas Prices

We construct a VAR model and Granger causality test to test the relationship between the GPG and gas prices. Tables 9 and 10 show that the GPG of a day's lag period has a significant positive impact on gas prices in South Australia and Victoria but has no significant impact in NSW and Queensland and the panel data. The GPG of 2 days lag period has a significant negative impact on gas prices in all regions and the panel data. The gas prices of a day lag period have a significant positive impact on the GPG in South Australia and Victoria. Still, they have no significant impact in NSW, Queensland, and panel data. But the GPG of 2 days lag period has a significant

Table 9 The relationship between gas-powered generation (GPG) and gas prices

	NSW	QLD	SA	VIC	Panel (FE)
	(1)	(2)	(3)	(4)	(5)
Dependent variable: Gas price					
L1. Gas price	0.660*** (0.016)	0.668*** (0.017)	0.750*** (0.016)	0.685*** (0.016)	0.687*** (0.008)
L2. Gas price	0.268*** (0.016)	0.212*** (0.017)	0.226*** (0.016)	0.258*** (0.016)	0.246*** (0.008)
L1. GPG	−0.001 (0.002)	−0.028 (0.026)	0.044*** (0.005)	0.006*** (0.002)	0.002 (0.002)
L2. GPG	−0.005** (0.002)	−0.064** (0.026)	−0.046*** (0.005)	−0.006*** (0.002)	−0.007*** (0.002)
Constant	0.167*** (0.019)	1.114*** (0.137)	0.070** (0.034)	0.095*** (0.015)	0.151*** (0.013)
Dependent variable: GPG					
L1. GPG	0.641*** (0.016)	0.933*** (0.017)	0.809*** (0.016)	0.603*** (0.017)	0.650*** (0.008)
L2. GPG	0.129*** (0.016)	−0.078*** (0.017)	−0.117*** (0.016)	0.015 (0.017)	0.089*** (0.008)
L1. Gas price	0.041 (0.117)	−0.014 (0.011)	0.112** (0.053)	0.348*** (0.127)	0.060 (0.040)
L2. Gas price	−0.344*** (0.015)	−0.044*** (0.011)	−0.077 (0.053)	−0.033 (0.126)	−0.137*** (0.040)
Constant	2.403*** (0.144)	1.529*** (0.091)	2.900*** (0.114)	2.412*** (0.118)	2.429*** (0.064)
N	**3,723**	**3,422**	**3,750**	**3,669**	**14,564**

Note ***, **, * are statistically significant at the 1%, 5%, 10% level
Source Authors' calculations

Table 10 Granger causality wald tests for gas-powered generation and gas prices

		H0: Gas-powered generation does not granger-cause gas price	H0: Gas price does not granger-cause gas-powered generation
NSW	chi2	13.757	40.351
	P	0.001	0.000
QLD	chi2	51.611	91.476
	P	0.000	0.000
SA	chi2	97.484	10.909
	P	0.000	0.004
VIC	chi2	10.453	43.193
	P	0.005	0.000

Source Authors' calculations

negative impact on gas prices in NSW, Queensland, and panel data, consistent with the results in Table 5.

Although the effect of independent variables 1 day lag period on dependent variables varies in different regions, the coefficients 2 days lag period are negative. So, the relationship between the GPG and gas price is roughly negatively correlated.

The results of the Granger causality Wald test show that the GPG does Granger-cause gas prices in all four regions, and gas prices also do Granger-cause GPG in all regions.

5   Policy Implications for ASEAN and Latecomers

With a total GDP of US $3.1 trillion in 2017, ASEAN is the fifth-largest economy in the world, only after the United States, China, Japan, and Germany. The ASEAN economy is expected to grow to US $12.25 trillion in 2050. Under the business-as-usual scenario (BAU), ASEAN's total final energy demand is expected to grow from 480 Mtoe in 2017 to 1,355 Mtoe in 2050, and its emissions will increase from 375 Mt CO_2 (Mt-C) equivalent to 1,216 Mt-C (Han and Kimura 2021). Although the share of electricity in ASEAN's total final energy consumption (TFEC) will increase modestly from 16.5% in 2017 to 20.65% in 2050 in BAU, the total electricity output will increase threefold from 1,041 to 3,439 TWh in BAU and 2,895 TWh in the alternative policy scenario (APS) during the same period.

Unfortunately, fossil fuels will still count for 72% of the generation mix even in the APS, while VREs will account for only 12.3% in 2050. Due to the low electricity share in the TFEC and the generation mix, emissions in ASEAN are expected to increase from 375 to 876 Mt-C in 2050 (Han and Kimura 2021). In the context of global consensus on fighting climate change, the ASEAN region needs to take immediate actions to reduce future carbon emissions through measures such as more gas use and renewable energies.

Given the high share of fossil fuels (78% share of oil, coal, and natural gas) in ASEAN's energy mix, ASEAN must advance the decarbonising process, which requires policy commitments and significant efforts. However, although Singapore has announced its plan to achieve net-zero emissions beyond 2050, many ASEAN countries have yet to set any net-zero emissions target.

Natural development in decarbonising energy mix is possible. Since VREs such as solar and wind have so far contributed negligible amounts (2.4% in 2020) to the power mix (Han et al. 2021), the future growth potential is there. Due to its low starting level, renewables such as biomass, wind, and solar are expected to increase largely by 93% due to upscaling renewable policy in ASEAN. Such rapid growth requires grid-stabilising techniques to accommodate the increasing penetration of VREs.

ASEAN's rich natural gas reserves provide a much-needed technical option to manage the challenges from large shares of VREs, but there is not a market to reward gas's role. Due to its flexibility in generation, natural gas generation can reduce

emissions (compared with coal power generation), provide power system flexibility, and maintain national security (compared with imported electricity). Natural gas accounts for 40% of the ASEAN generation mix, an asset for advancing VREs. Given the urgent and critical need for transitioning to low-carbon energies, especially to decarbonise the grid electricity sector, many ASEAN governments will need to implement deeper electricity market reforms to accommodate clean and renewable electricity.

ASEAN is stepping behind Australia's electricity sector from three perspectives: the linearisation of the electricity sector, development of electricity markets, and increasing penetration of renewable energy. Many ASEAN countries embarked on electricity reform from the centrally or vertically integrated stated ownership to the hybrid market-based system in which state-owned utility remains the 'single buyer' and the private sector joins in the supply of electricity as 'independent power producers'. However, the ASEAN electricity markets are not competitive in most countries except the Philippines and Singapore. Given the current electricity market in ASEAN, attracting new investment in this sector is very hard. It is especially difficult to introduce the high share of renewables and innovative technologies such as smart grids, which will allow more renewable energy penetration technically.

Therefore, the Australian experience can inform ASEAN on electricity sector development and renewable energy. In the absence of competitive markets, natural gas generation, despite being flexible, would not deliver the flexibility as contractual and other institutional constraints prevent them from being a mate of VREs.

Our estimation results of Australia's NEM indeed suggest that a well-functioning electricity market can reward the flexible role of natural gas, and a competitive market is certainly conducive to the development of renewable energies. Therefore, we could generate the following implications from our study.

First, ASEAN should leverage the flexible role of natural gas. Such significant role in the ASEAN generation mix is an asset. Thus, efforts should be made to generate gas pricing signals to timely react to power market needs.

Second, ASEAN should continuously liberalise its electricity markets and establish a merit-order competitive electricity market. Confirmed significant roles of the electricity market in promoting the GPG can shed light on ASEAN's future policies on the electricity markets.

Third, ASEAN needs to continuously promote regional integration as another cost-effective policy to handle the increasing penetration of VREs. ASEAN countries have complementary energy resources, and the abundance of hydropower resources in the Greater Mekong Subregion is an asset to offset the volatilities from VREs. Therefore, the penetration of solar PV and wind in ASEAN could be advanced by power connectivity and trade within ASEAN (IRENA 2018; Shi 2016).

A framework that can combine the gas and electricity markets should be established. Due to the increasing penetration of VREs, power systems are relying more on the flexibility roles of the GPG, which will gradually link the currently separated gas and electricity markets (Chen et al. 2018; Heinen et al. 2017). However, the existing market framework is not conducive: neither reliable nor efficient and also economically unfriendly to GPG investors (Heinen et al. 2017). A framework that

combines the two markets and properly prices the scarce resources, e.g. gas transmission capacity, is required to efficiently allocate resources while satisfying the demand (Heinen et al. 2017).

6   Conclusion

Natural gas is considered a natural partner for VREs due to its flexibility in generation at affordable prices. However, whether the GPG can play such a flexible role in the generation mix depends on such flexibility being rewarded. A competitive electricity market rewards peak prices to GPG and is expected to be a reason to liberalise the electricity markets. Empirical evidence of a competitive market's role in GPG development can inform future electricity market reform, mainly in developing countries.

This chapter theoretically analyses the relationship between the competitive electricity market and the GPG and hopes to take Australia's energy transformation as an example to give ASEAN some constructive suggestions. First, based on the literature review, this chapter puts forward several assumptions on the relationship between the electricity market and Australia's GPG. Then it verifies the hypotheses by constructing OLS, panel, and VAR models, and the Granger causality test with the daily data from AEMO.

The empirical tests fully support the hypotheses: (i) that the GPG is negatively related to generation from VREs and positively related to electricity demand gap and electricity prices, (ii) spot gas prices are positively related to electricity prices and electricity demand, and (iii) spot gas prices have mixed relationships with the GPG. Therefore, the findings suggest that ASEAN should boost gas use and continue electricity market liberalisation and regional electricity market integration.

References

AEMO (2021). 2021 Gas Statement of Opportunities

Atwa YM, El-Saadany EF (2010) Optimal allocation of ESS in distribution systems with a high penetration of wind energy. IEEE Trans Power Syst 25:1815–1822. https://doi.org/10.1109/TPWRS.2010.2045663

Australian Energy Market Operator (AEMO) (2010) An introduction to Australia's national electricity market. Energy Market Authority, Singapore

Australian Energy Regulator (AER) (2021) State of the energy market 2021. Australian Competition and Consumer Commission, Melbourne

Australian Government (2020) Gas-fired recovery. https://www.pm.gov.au/media/gas-fired-recovery. Accessed 20 Aug 2021

Bolinger M, Wiser R, Golove W (2006) Accounting for fuel price risk when comparing renewable to gas-fired generation: the role of forward natural gas prices. Energy Policy. https://doi.org/10.1016/j.enpol.2004.07.008

Chen R, Wang J, Sun H (2018) Clearing and pricing for coordinated gas and electricity day-ahead markets considering wind power uncertainty. IEEE Trans Power Syst. https://doi.org/10.1109/TPWRS.2017.2756984

Csereklyei Z, Qu S, Ancev T (2019) The effect of wind and solar power generation on wholesale electricity prices in Australia. Energy Policy. https://doi.org/10.1016/j.enpol.2019.04.007

Department of Industry Innovation and Science (2021) Australian energy satististics. https://www.energy.gov.au/government-priorities/energy-data/australian-energy-statistics. Accessed 23 Oct 2021

Devlin J, Li K, Higgins P, Foley A (2017) Gas Generation and Wind Power: A Review of Unlikely Allies in the United Kingdom and Ireland. Renew Sustain Energy Rev. https://doi.org/10.1016/j.rser.2016.11.256

DISER (2021) National electricity market. https://www.energy.gov.au/government-priorities/energy-markets/national-electricity-market-nem. Accessed 30 Oct 2021

Grafton RQ, Shi XR, Cronshaw I (2018) "Making Cents" of the Eastern Australian gas market. EconPapers 37:42–54. https://doi.org/10.1111/1759-3441.12194

Guidolin M, Alpcan T (2019) Transition to sustainable energy generation in Australia: interplay between coal, gas, and renewables. Renew Energy 139:359–367. https://doi.org/10.1016/j.renene.2019.02.045

Han P, Kimura S (2021) Energy outlook and energy saving potential in East Asia 2020. Economic Research Institute for ASEAN and East Asia, Jakarta

Han P, Kimura F, Arima J (2021) ASEAN's towards: energy and sustain. 13:1–29. https://doi.org/10.3390/su13052819

Heinen S, Hewicker C, Jenkins N, McCalley J, O'Malley M, Pasini S, Simoncini S (2017) Unleashing the flexibility of gas: innovating gas systems to meet the electricity system's flexibility requirements. IEEE Power Energy Mag 15:16–24. https://doi.org/10.1109/MPE.2016.2621838

Hörnlein L (2019) The value of gas-fired power plants in markets with high shares of renewable energy: a real options application. Energy Econ 81:1078–1098. https://doi.org/10.1016/j.eneco.2019.04.013

IRENA (2018) Renewable energy market analysis: Southeast Asia. IRENA, Abu Dhabi

Poyrazoglu OG, Poyrazoglu G (2019) Impact of natural gas price on electricity price forecasting in Turkish Day-Ahead Market. In: Proceedings—2019 IEEE 1st global power, energy and communication conference, GPECOM 2019, pp 435–39. https://doi.org/10.1109/GPECOM.2019.8778514

Qadrdan M, Chaudry M, Wu J, Jenkins N, Ekanayake J (2010) Impact of a large penetration of wind generation on the GB gas network. Energy Policy. https://doi.org/10.1016/j.enpol.2010.05.016

Shi X (2016) The future of ASEAN energy mix: a SWOT analysis. Renew Sustain Energy Rev 53:672–680. https://doi.org/10.1016/j.rser.2015.09.010

The Guardian (2020) Why is Australia building a $600 m gas power plant as world experts warn against fossil fuels? The Guardian