Economics Working Paper Series

2019 - 09

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March 2019

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29 March 2019

Abstract:

Our paper investigates the effect of wind and utility-scale solar electricity generation on wholesale electricity prices in Australia over 2010-2018. We use both high frequency (30-minute) and daily datasets for the Australian National Electricity Market (NEM). We estimate autoregressive distributed lag models (ARDL) to decompose the merit order effect of wind and utility-scale solar PV generation over time and across states. We find that an extra GW of dispatched wind capacity decreases the wholesale electricity price by 11 AUD/MWh at the time of generation, while solar capacity by 14 AUD/MWh. The daily merit order effect is lower. We show that the wind merit order effect has been increasing as a function of dispatched wind capacity over time. Despite of this, wholesale electricity prices in Australia have been increasing, predominantly driven by the increase in gas prices. Our findings further strengthen the evidence of the merit order effect of renewable energy sources, with important implications for the current energy policy debate in Australia.

Keywords: electricity price; merit order effect; natural gas price; solar generation; wind generation.

Acknowledgements: We thank two anonymous reviewers, as well as seminar participants at the Arndt-Corden Department of Economics at the Australian National University, the Tasmanian School of Business and Economics at the University of Tasmania, and the participants of the WUN Workshop on ‘The Political Economy of Energy Transition Toward Renewables’ at the Chinese University of Hong Kong for useful comments.

1. Introduction

In line with developments in many countries around the world, electricity generation capacity based on wind turbines (WT) and solar photovoltaic cells (PV) has been rapidly increasing over the last decade in Australia. WT capacity currently stands at around 5 GW (AEMO, 2018b), and utility scale and rooftop PV around 6 GW in Australia's National Electricity Market (NEM). This is relatively small when subject to international comparisons, but it comprises a significant proportion of the total electricity generation capacity in Australia. The growth in WT and utility scale PV capacity has been dramatic over the last 15 years (Table 1).

Table 1. Utility scale solar photovoltaic (PV) and wind turbine (WT) generation capacity (in MW) and yearly growth rates (%) for the Australian National Energy Market, 2012-2018

	2012	2013	2014	2015	2016	2017	2018
Utility Scale PV (MW)		1.50	2.03	176.90	233.00	322.60	1483.95
Year on Year Growth			35%	8614%	32%	38%	360%
WT (MW)	2402.65	2741.4	3143.15	3688.65	3830.15	4462.15	5721.75
Year on Year Growth		14%	15%	17%	4%	17%	28%

Note: NEM generation capacity data includes the states of New South Wales, Victoria, South Australia, Queensland and Tasmania. NEM data does not include small scale (rooftop) PV capacity. Source: AEMO (2018b), Commonwealth of Australia (2018)

While WT capacity was growing very fast until the end of the first decade of this century, utility-scale PV began overtaking subsequently.[1] This pattern is observed in many other countries around the world. Figures 1 and 2 show the evolution of wind and large-scale solar PV based electricity generation.[2]

[1] Small-scale PV (rooftop, or distributed PV) generation capacity is not included in the NEM statistics, because the electricity generated through the small-scale PV is not allocated through the wholesale market. For this reason, small-scale PV is not a part of our investigation. Nevertheless, there has been significant growth in small-scale PV in Australia over the last decade (Clean Energy Regulator; http://www.cleanenergyregulator.gov.au)

[2] While installed capacity has been increasing significantly, there have been significant delays in commissioning, most notably in Queensland

Fig 1. Wind turbine (WT) based electricity generation in Australia, 2010-2017. Data source: AEMO (2018a, 2018b)

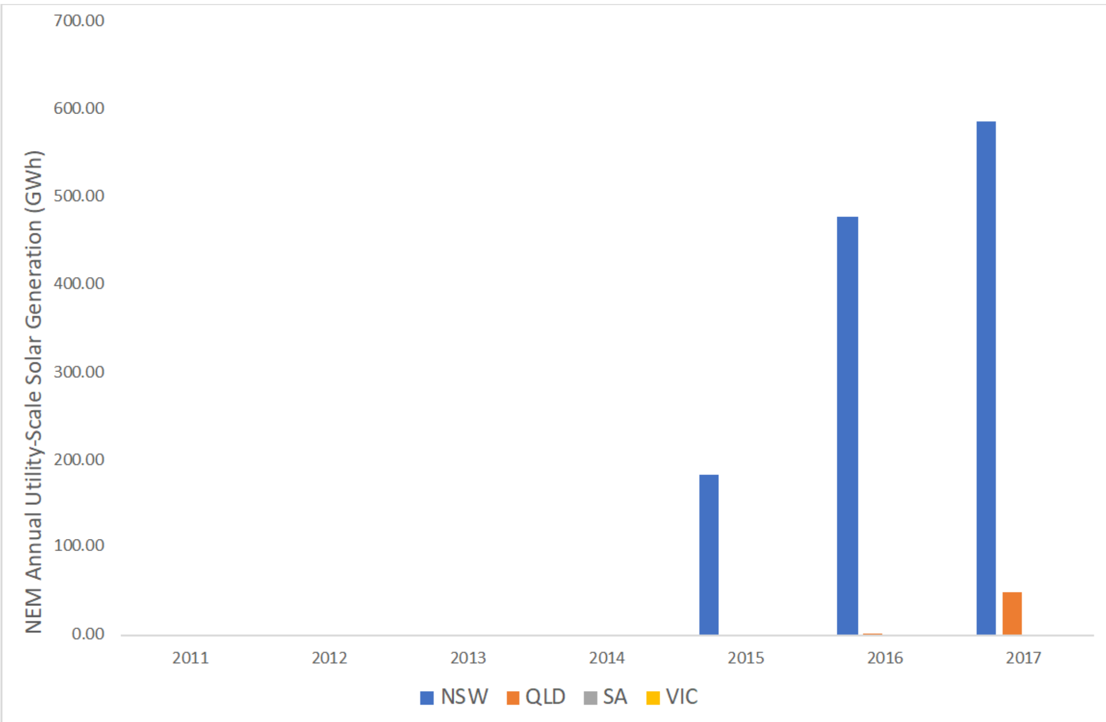

Fig 2. Utility-scale solar PV based electricity generation in Australia, 2010-2018. Data source: AEMO (2018a, 2018b)

The rapidly increasing penetration of WT and PV opens up pressing questions about the effects it may have on existing electricity systems. These questions range from the short- and long-run effects on electricity wholesale and retail prices, through the reliability of electricity supply, to the effects on investment incentives in electricity generation facilities. While these issues have been pertinent throughout the world, they have significant political salience in Australia, where a heated debate is taking place around national energy policy, which inevitably encompasses the debate on climate change (Pearse, 2016). These issues have divided the public for most of the last 20 years, and have been heavily present in political battles, including elections and changes in government and opposition leadership (Crowley, 2017).

A key driving factor of the debate around energy policy in general and the role of renewables in particular, have been the rapidly increasing electricity prices, at both wholesale (Figure 3) and retail levels over the last 10 years.

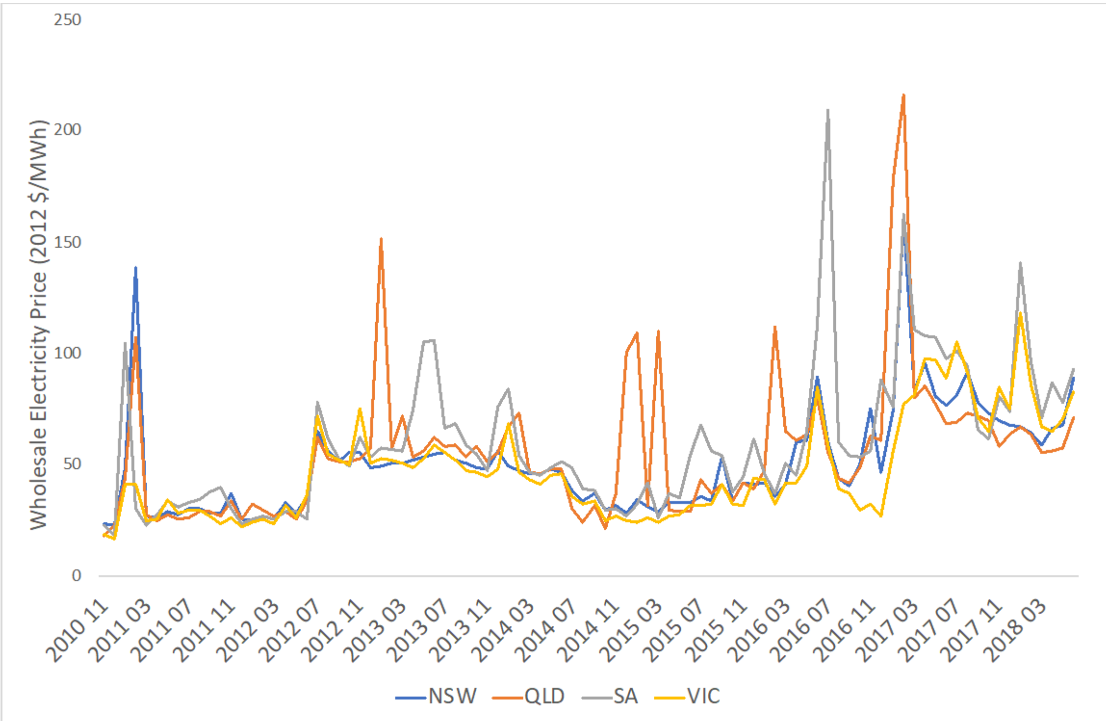

Fig 3. Wholesale electricity prices in Australia 2010-2018 (in 2012 AUD). Source: AEMO (2018a)

As this phenomenon has coincided with a period of rapid penetration of WT and PV generation, the question of a causal relationship between renewable-powered generation and increasing wholesale electricity prices has surfaced. Evidence for such causality is however lacking in the scholarly literature. To the contrary, there appears to be a large body of evidence stating that the increased penetration of renewables is expected to lead to a reduction in wholesale electricity prices.

In countries with competitive (or liberalized) electricity markets, wholesale electricity prices are determined by equilibrium between supply and demand, through the process of generators putting bids for supplying electricity to the market. Renewable generators bid into the market at a very low or zero marginal cost, thereby displacing high marginal cost bids, which are usually associated with gas fired peak-load generators. The wholesale price is usually at or above the marginal cost of the last supplier needed to satisfy demand (Borenstein, 2000). Increases in zero, or very low marginal cost generation from renewable sources are therefore expected to decrease the wholesale electricity price, at least in the short-run. This is known as the merit-order effect (Sensfuß, et al. 2008).

In this paper, we test the existence of the merit-order effect (MOE) in the Australian wholesale electricity market. Evidence in favour of the merit order effect will rebuke the claims that increased renewable generation results in higher wholesale electricity prices and will shed further light on the actual causes of such price increases. We also examine how the merit-order effect has been changing over time, as the significance of WT and PV within the Australian electricity generation profile has changed. Specifically, we examine the effects of increasing PV generation relative to WT generation on the merit order effect of both solar and wind generation.

Consequently, we ask the following questions in this paper: Is there a merit order effect in the Australian wholesale electricity market? Has the magnitude of this effect been changing as the shares of WT and PV generation increased over time? We answer these questions empirically. Our strategy for testing the merit order effect is to use high frequency (30 minute and daily) electricity generation and price data for the Australian National Electricity Market over 2011-2018. We use these data to estimate econometric (ARDL) models that relate the wholesale electricity price to the electricity generated by WT and PV, while controlling for other important factors that affect the wholesale electricity price. A key among those factors is the wholesale price of natural gas (NG).

Natural gas fired peak load generators are often the last bidders in liberalized electricity markets, such as the NEM. Therefore, in deregulated markets, natural gas prices tend to determine wholesale electricity prices (Borenstein and Bushnell, 2015). Natural gas prices have been increasing dramatically over the recent years in Australia, predominantly due to the opening up of export capacity, and the integration of the Australian NG market with international markets, resulting in lower local supply in the absence of domestic gas reservation requirements (Figure 4). High NG prices put an upward pressure on wholesale electricity prices, as the marginal cost of operating gas turbines increases.[3]

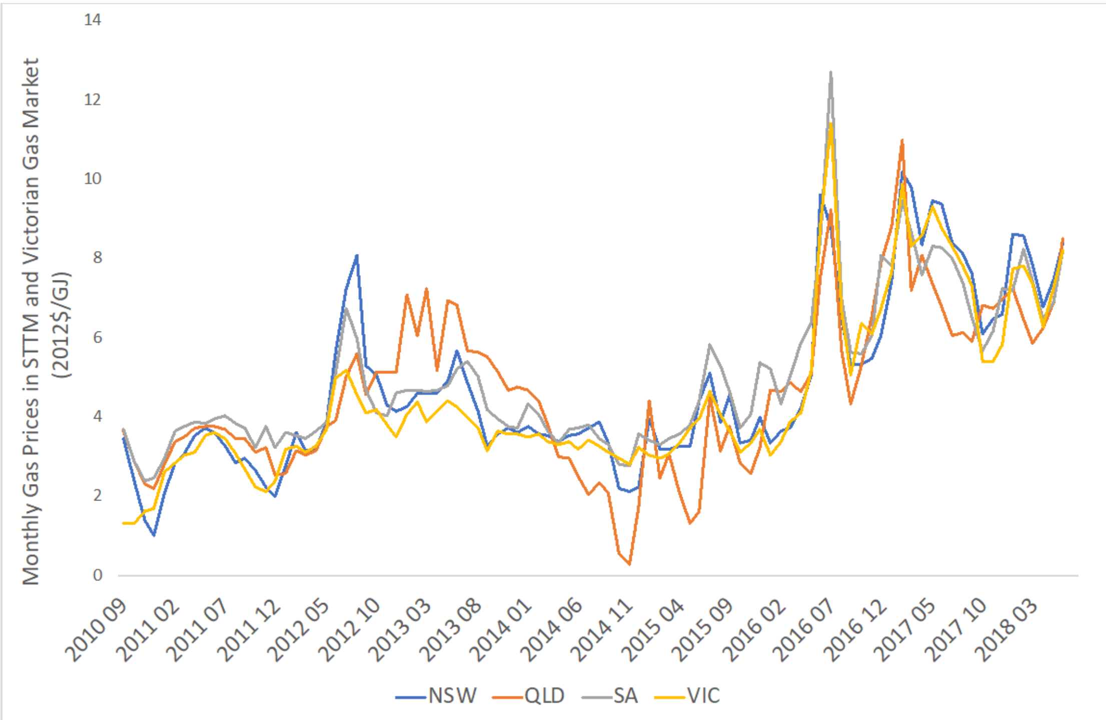

Fig 4. Wholesale gas prices in Australia 2010-2018, (in 2012 AUD). Source: AEMO (2018a)

This phenomenon could be possibly counteracting or outweighing the price reductions arising from the merit order effect of renewable generation, thus causing the wholesale electricity prices to increase. We test this hypothesis by comparing the merit order effect and the NG price effect in the Australian wholesale electricity market. Finding evidence that the NG price effect is greater than the merit order effect

[3] The focus of policy in Australia has traditionally been on enabling or facilitating NG without much attention being paid to the possible effects of increasing NG prices. However, in the wake of rising prices, the Australian Government issued a customs amendment to regulate the export of LNG in 2017 (https://www.legislation.gov.au/Details/F2017L00826)

would help partially explain why wholesale electricity prices in Australia have increased over the recent period. Apart from the NG price effect more profit-maximizing bidding practices from both coal and gas fired generators after 2014 also contributed to increased wholesale prices.

Our findings in brief are as follows. We find a strong contemporaneous merit order effect of WT and PV based generation in the Australian wholesale electricity market. We find that an extra GW of dispatched wind capacity decreases the wholesale electricity price by 11 AUD/MWh, while dispatched solar capacity by 14 AUD/MWh. Increases in the magnitude of the wind MOE coincide with increases in dispatched capacity, while the relationship between solar capacity and the magnitude of the solar MOE albeit negative, is not found to be significant. We do find however that increases in wind dispatched capacity tend to be associated with decreases in the magnitude of the solar MOE. We also find that a 1 GWh increase in daily wind generation would be associated with approximately 1 AUD/MWh price decrease in the daily average prices. Similarly, a 1 GWh increase in solar generation during a day is associated with 2.7 AUD/MWh decrease in the daily wholesale electricity prices. The price of NG has a strong positive effect on wholesale electricity prices in Australia. One AUD/GJ increase in the NG price is expected to increase wholesale electricity prices by about 5 AUD/MWh.

Our findings suggest that the continued penetration of renewables is likely to put an ongoing downward pressure on wholesale electricity prices in the future despite the recent increases, which can be mainly attributed to increases in NG prices. These findings suggest that energy policy in Australia should create favourable conditions for further increasing the share of renewables in the electricity generation mix.

The paper is structured as follows: Section 2 introduces the relevant literature and places this paper within it. Section 3 describes the data and the methods. Section 4 presents our findings and Section 5 discusses the policy implications of these findings.

2. Literature review

Evidence from a large number of studies has shown that electricity from intermittent renewable energy sources, such as WT and PV reduces the wholesale electricity price in deregulated or liberalized electricity markets. Jensen and Skytte (2003) were among the first to document the relationship between the proportion of renewable energy in energy generation mix and the wholesale price of electricity. Their findings showed that a greater share of renewable energy in the total electricity generation mix can lead to a decrease in the wholesale electricity price.[4]

Several studies identify the MOE for wind and/or solar electricity generation using various approaches, the most important of which are agent-based modelling (eg.: Senfuss et al., 2008; Bublitz et al., 2017), power flow and dispatch models (eg.: Bell et al., 2017, Cebulla and Fichter, 2017; Pirnia et al., 2011; Martinez-Anido et al., 2016, Hirth, 2013), and various econometric techniques (eg.: Gelabert et al., 2011; Mulder and Scholtens, 2013, Tveten et al., 2013, Wuerzburg et al., 2013 Claudius et al., 2014a and 2014b, Ketterer 2014, Kyritsis et al., 2017, Clo et al., 2015; Woo et al., 2011 and 2016).

Econometric approaches however make up the vast majority of the literature. Clò et al. (2015) examined the merit order effect of wind and solar electricity generation on the wholesale price in the Italian market, finding lowered prices with higher renewables, but higher volatility. Clò et al. (2015) found that each GWh increase in average generation from WT reduces the wholesale electricity prices by 4.2€/MWh in the Italian electricity market. Azofra et al. (2014) find spot price decreases between 7.42 and 10.94 €/MWh for a wind power production of 90% and 110% of the real one, respectively.

Using an AR (1) model with 15-minute zonal price, Woo et al. (2011) found evidence for the merit order effect: a GWh marginal increase in WT generation led to

[4] That study challenged the conventional wisdom at the time, which postulated that increased renewable electricity generation would lead to increased electricity prices. The paper inspired a substantial subsequent research effort on investigating the merit order effect of renewables on electricity prices.

$3.9/MWh reduction the spot electricity price in Huston, $6.1/MWh in the North Zone, and $15.3/MWh in the West Zone of the ERCOT ISO in the United States.

Using a GARCH model from 2006 to 2012 and a three-year rolling window, Ketterer (2014) found that one percent increase in the wind share of total generation on average leads to 1.46% decrease in the electricity price in Germany. Ketterer (2014) also found that the merit order effect of WT diminished after the fast growth of solar PV. Similarly, Cludius et al. (2014b) found that the merit order effect of WT ranges from 0.97 to 2.27 €/MWh for every additional GW wind dispatched capacity, and the merit order effect of PV ranges from 0.84 to 1.37 €/MWh for every additional GW solar dispatched capacity. The empirical findings from the literature are consistent across many European countries and the USA in that there is a strong evidence that WT and PV sourced electricity lowers the wholesale electricity price. In addition, there is some evidence that the merit order effect of renewable powered electricity generation strengthens over time due to the growing generation capacity (Sensfuß et al. 2008).

While much of the literature focuses on the marginal short-run effect of increasing renewable energy penetration on the electricity market, there have been very few studies that evaluate the long-run effect of growing renewable electricity generation. Due to the intermittent nature of renewables, PV generators can only operate during the daylight and under conditions of moderate or no cloudiness[5], and WT only produce electricity when certain wind speed is reached. As a result, WT and PV generated electricity needs to be complemented by other type of generators (Hirth, 2013). In the short-run wind and solar energy can lower the wholesale electricity price by displacing more expensive generators (Hirth, 2013). However, the long-run merit order effect is much less clear. Evidence from the California Independent System Operator (CAISO), shows that the long-run effect of renewables on wholesale electricity prices might be different from their short-run effects (Bushnell and Novan, 2018). Bushnell and Novan (2018) find that solar energy only reduces the wholesale price during the daylight time and increases it during shoulder-hours.

[5] Solar PV units are capable of producing (reduced) amounts of electricity in moderately cloudy conditions due to the presence of diffused horizontal irradiance. This is not the case for solar thermal generators, which require direct solar radiation.

While literature has shown that the merit order effect of wind and/or solar exists in many countries in Europe (eg.:Sensfuß et al., 2008; Clò et al., 2015; Würzburg et al., 2013) and in the US (eg.: Fell and Kaffine, 2018; Woo et al., 2011; Woo et al., 2016), there is a limited evidence showing similar merit order effect in Australia (Cutler et al., 2011; Cludius, et al., 2014a; Forrest and MacGill, 2013; McConnell et al., 2013; Bell et al., 2017, Simhauser, 2018). Forrest and MacGill (2013) estimate that the total merit order effect of WT resulted in wholesale electricity price reduction of \$8.05/MWh for South Australia and of \$2.73/MWh for Victoria in the period 2009–2011. There are studies suggesting that WT and PV are complementing each other well in electricity generation (Monforti et al., 2014), but the effect of changing share of WT and PV within the renewable energy mix in Australia has not yet been investigated.

The current paper contributes to the literature on the merit order effect in some important ways. Firstly, it investigates the merit order effect using high frequency (30-minute) electricity generation and price data over a long period of time (2010-2018). Electricity data that combine high frequency of observations and a long time series provides advantages in testing the merit order effect. The nature of the data allows us to more precisely measure the contemporaneous effect of WT and PV on wholesale electricity prices and volatility.

Secondly, our paper is the first study on the Australian wholesale electricity market to examine the merit order effect of both WT and PV simultaneously. Previous studies (Cutler et al., 2011; Forrest and MacGill, 2013; Cludius, et al., 2014a) have only looked at wind turbines, which is understandable given that utility-scale PV electricity generation has been a rather recent development in Australia. By jointly investigating the effect of WT and PV, we are able to determine how the merit order effect has changed as the relative importance of WT and PV have changed over time. Thirdly, this paper presents an empirical study that finds evidence of the MOE in a market with increasing wholesale electricity prices. Most of the previous literature refers to cases where the MOE has been paralleled with reduction in wholesale prices.

3. Models and data

3.1 Models

We estimate the effect of utility-scale solar and wind generation on real-time and daily wholesale prices in the Australian National Electricity Market. We cover four states, including New South Wales (NSW), Victoria (VIC), Queensland (QLD), and South Australia (SA). The Australian Capital Territory or Tasmania are not included in the dataset, as they are much smaller both in terms of generation and electricity use than the other four states.

High frequency (30-minute) price and generation data is best suited for estimating the contemporaneous merit order effect, while data using higher aggregation (daily aggregate data) allows the testing of the non-contemporaneous effect of renewable generation on electricity prices. Non-contemporaneous merit-order effects are important, as research (Bushnell and Novan, 2018) suggest that high levels of solar generation might be connected to increased shoulder-energy prices. Distributed solar (PV) data is not included in the AEMO dataset, therefore increases in distributed PV generation show up as negative demand during the hours of solar-irradiation.

3.1.1. Contemporaneous merit order effect – high frequency data

We estimate the following autoregressive distributed lag regression model to approximate the contemporaneous merit order effect of WT and utility-scale PV generation:

$$P_{i,t} = \alpha + \beta_1 S_{i,t} + \beta_2 W_{i,t} + \boldsymbol{\xi} \sum_{j=0}^{2} L_{i,t-j} + \boldsymbol{\lambda} \sum_{j=1}^{2} P_{i,t-j} + \boldsymbol{\gamma D} + \varrho_y + \mu_i + \varepsilon_{i,t}$$

(1)

Where t=30 min and:

- $P_{i,t}$ is the average wholesale electricity price in a given state (*i*), over a thirty-minute interval *(t)*.
- $S_{i,t}$ denotes average 30-minute dispatched capacity from solar utility plants, measured in MW, while $W_{i,t}$ denotes average dispatched capacity from wind

turbines in MW.

- $L_{i,t}$ measures the average electricity demand in a given 30-minute period.
- **D** is a vector of indicator variables including dummies for the time of day (30-minute periods), days of the week (working days, weekends, and public holidays) and months of a year.
- ϱ_y is an annual time trend.
- μ_i denotes fixed effects for the four Australian states (NSW, VIC, QLD and SA).

We also estimate Eq (1) on the state-level. The autoregressive distributed lags include two lags of the wholesale prices and the demand. We determined the lag length by including only lags with statistically significant coefficients. A number of indicator variables were added to the regression, that control for daily, weekly, and seasonal patterns in electricity use. For example, electricity demand is lower during the night, on weekends, but tends to be generally higher during the summer. The time trend controls for common changes in prices attributed to changes in federal regulatory environment, market and technological changes, and to weather and climate patterns. These might include increasingly profit-maximising bidding practices (market conditions), as well as the increase in national average temperatures since 2014. State fixed effects control for differences in economic conditions, and state regulations. We estimate a range of models based on Eq.1 with various fixed effect controls.

A number of previous studies attempted to address the merit order effect by estimating a model in levels or log-levels (Cludius et al., 2014b; Clo et al., 2015).
Studies that addressed the autoregressive nature of the wholesale electricity price by including a lagged dependent variable in the model include Cludius et al. (2014a), Forrest and MacGill (2013), Woo et al. (2011), Ketterer (2014), and Woo et al. (2016). One possible caveat of this approach is the known presence of a dynamic panel bias (Nickell, 1981; Hahn and Kuersteiner, 2002).

A major critique of estimating our model in levels (with or without a lagged dependent variable) is that it could lead to spurious results if the variables exhibit non-stationarity (Davidson and MacKinnon, 2009). Therefore, we carried out panel unit root tests, where applicable (Im et al., 2003), as well as augmented Dickey-Fuller (ADF) unit root tests (Dickey and Fuller, 1979) on the state-level time series. While we can reject the null hypothesis of unit roots in all cases, we also find that many of the variables show very highly autoregressive, or near-unit root properties. This gives justification to our decision to include lags of both the wholesale electricity price and the electricity demand in Eqs. (1) and (2).

Another common bias in the estimation of the merit order effect originates from possible endogeneity related either to reverse causality or to omitted variables (Bushnell and Novan, 2018). As half-an-hourly or daily variation in WT and PV electricity generation is entirely driven by exogenous factors, such as windiness and solar irradiance (assuming no curtailment)[6], we do not have to worry about reverse causality between renewable generation and wholesale electricity prices in the short-run.

The average or aggregate electricity demand is another possibly suspect variable for reverse causality. However, as the NEM matches production to satisfy demand in 5-minute periods, it is very unlikely that high wholesale electricity prices or spikes in electricity prices could influence national or state-wide demand in a 5-minute time frame, or even during a day. It is known that electricity demand is highly inelastic to retail prices in the short run (Burke and Abayasekara, 2018), however in the long-run electricity consumption might react to persistently higher retail electricity prices. While wholesale prices are only a fraction of the retail electricity price, a persistent increase or decrease in wholesale prices, if passed onto the retail prices might influence long-run demand. Theoretically, higher shares of renewables in the generation mix might decrease wholesale prices, which in turn might decrease retail prices and lead to an increase in demand.

Another important consideration relates to omitted variables, more precisely to rooftop PV generation, which is currently not included in the AEMO dataset, because electricity generated by rooftop PV is not channelled through the NEM bidding process. Rooftop PV generation occurs at the same time as utility-scale PV generation, but instead of showing up as additional supply, it enters the supply –

[6] While wind and solar curtailment has been increasing in Australia, it is still relatively low compared to other countries. The most affected state was South Australia with a highest reported curtailment of 150 GWh (solar and wind) in Q3 of 2018 (AEMO, 2018c).

demand relationship as "negative demand", when it comes to determining prices, thereby also inducing a merit order effect[7].

Another econometric issue is that wholesale prices in the NEM can range between the floor price of -1000 $/MWh to the cap price of 14200 $/MWh. Several studies, including Cludius et al. (2014a), Cutler et al. (2011), Forrest and MacGill (2013), truncated the prices when estimating the merit order effect. These studies used a price range between 1 and 415 $/MWh, representing the estimated lowest and the highest marginal cost of generation in the NEM. The rationale for this is that prices beyond or below these limits are due to market forces and strategic market behaviour.[8] We have however decided not to truncate the data, in order to allow for the possibility that market behaviour might be driven in part by the WT and PV generation.

3.1.2 Daily merit order effect – aggregated data

While the majority of studies looked at the short-run or contemporaneous effect of marginal renewable generation on wholesale electricity prices (Cludius et al., 2014a; Forrest and MacGill, 2013; Woo et al., 2011; Ketterer, 2014; Woo et al., 2016 and Fell and Kaffine, 2018), we are also interested in investigating the daily effect using aggregate daily data, as there may be notable differences when compared to the half-hourly data (Bushnell and Novan, 2018). Daily data also allows us to estimate the effect of the NG price variations (for which data are only available in daily format) on the wholesale electricity price, which is of particular importance in case of the Australian NEM, given the recent hikes in NG prices.

We test the effect of aggregate daily solar and wind generation (expressed in MWh) on the average daily wholesale electricity prices, by estimating the following regression:

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[7] The changing electricity landscape requires deliberating on the role of batteries. While batteries only constitute a small share of the electricity mix, their role is twofold. During low-prices (off peak and likely high wind generation times) they are charging and thus add to the demand. During high priced period (high solar generation and peak hours) they are discharging and thus adding to the supply.
The effect is currently marginal, however with growing solar and wind capacity, battery storage is also expected to increase.

[8] It has to be noted that the regulatory framework (price caps, floors, as well as generation constraints) may also impact on prices, as well as renewable generation quantities, and can be regarded as potentially omitted variables.

$$P_{i,d} = \alpha + \beta_1 S_{i,d}^A + \beta_2 W_{i,d}^A + \theta PG_{i,d} + \boldsymbol{\xi} \sum_{j=0}^{2} L_{i,d-j}^A + \boldsymbol{\lambda} \sum_{j=1}^{2} P_{i,d-j} + \boldsymbol{\gamma D} + \varrho_y + \mu_i + \varepsilon_{i,d}$$

(2)

where d = one calendar day and,

- $P_{i,d}$ denotes daily average prices generated by averaging 30-minute intervals.
- $S_{i,d}^A$ and $W_{i,d}^A$ denote aggregate daily utility-scale solar and wind generation in MWh, $L_{i,d}^A$ is daily aggregate demand
- $PG_{i,d}$ denotes the daily NG prices
- $\boldsymbol{D}$ is a vector of indicator variables including dummies for the days of the week (working days, weekends, and public holidays) and months of a year.
- ϱ_y is an annual time trend.
- μ_i denotes fixed effects for the four Australian states (NSW, VIC, QLD and SA).

In this case the units can be interpreted as the actual daily demand (L), solar (S) and wind (W) generation expressed in MWh.

WT and PV are expected to reduce the wholesale prices much less on the daily level because they generate only for a limited period of time during the day. It is also possible that renewable generation in a day can require significant peak-load capacity from generators that are more expensive (e.g. gas fired turbines). Therefore, we include the natural gas price similarly to Bushnell and Novan (2018), as often natural gas fired turbines are the marginal bidders in the market, therefore natural gas prices tend to drive electricity prices in wholesale markets (Borenstein and Bushnell, 2015). While the majority of the NG based generation is delivered within the framework of long-run contracts, we assume that long-run fluctuations in NG market prices are reflected in the cost structure of the generators (including contract prices). As NG prices have been recently increasing in Australia, we expect to find a significant positive effect of NG prices on wholesale electricity prices, which is possibly stronger than the merit order effect.

Apart from natural gas price changes, any change in the generation mix will also have an effect on wholesale electricity prices. Recently, Australia has seen some retirements of coal-fired generators (the most prominent of which was Hazelwood in Victoria). After such closures the demand is likely to be fulfilled by a mixture of renewable and natural gas-fired electricity supply. Given the importance of natural gas prices in determining wholesale electricity prices, closures of coal-fired powered stations are likely to put an upward pressure on electricity prices predominantly via the effect of high natural gas prices.

Another important factor is the availability of hydro-generated electricity throughout the year. Australia has experienced extended periods of draught, often spanning over several years. Insufficient rainfall and low streamflow conditions simultaneously decrease the available water supply for electricity generation and increase the demand for electricity, due to more intensive irrigation and groundwater pumping. While it is beyond the scope of this paper to examine the impacts of draughts on electricity prices, the topic merits further research in the future.

All models and their variations were estimated using a robust least-squares estimator, with heteroscedasticity consistent (HAC) standard errors.[9]

3.1.3 Change in the merit order over time

Another important question is how past changes in renewable electricity capacity growth influenced the merit order effect over time. In particular we are investigating the effect of the changing share of WT and PV generation on the merit order effect. To answer this question, we estimate equation (1) for each year from 2010 and 2018 and for each month from November 2010 to June 2018. We use the monthly MOE coefficients obtained from the 30-minute dataset, to regress these on the average dispatched WT and PV capacity in the NEM in a given month. This is presented in Eq. 3:

$$MOE_m^G = \beta_1 S_m + \beta_2 W_m + \varepsilon_m$$

(3)

[9] We used Stata's reghdfe command with HAC standard errors in our main tables (Correia, 2016). It is notable that these standard errors will be inconsistent, if for every fixed effect, the other dimension is fixed. Therefore as a robustness check, we also present the results using xtreg, fe robust that calculates clustered standard errors.

where G denotes the type of merit order effect: wind or solar, and m stands for the month. S is the average of the monthly dispatched solar capacity in the NEM (calculated as the average of the 5-minute dispatched capacities in a month), and W is the average of the monthly dispatched wind capacity in the NEM. The above equation thus estimates how the merit order effect changes with the change in average monthly (dispatched) capacities.

3.2 Data

Data covers four Australian states that are part of the NEM[10] including New South Wales (NSW), Victoria (VIC), Queensland (QLD), and South Australia (SA). The Australian Capital Territory or Tasmania, which are also part of the NEM are not included in the dataset because the ACT has no generation capacity, whereas Tasmania is largely operating as a separate market, despite the undersea interconnector that connects it to the NEM. In addition, the population of ACT and Tasmania are much smaller than that of the other four states that are considered.

We constructed our state-level panel datasets from November 1, 2010 to June 30, 2018: one dataset on a 30-minute basis (the average of six 5-minute periods), and another on a daily basis. All NEM market data were obtained from the Australian Energy Market Operator (AEMO, 2018a). These include 5-minute dispatch prices and 30-minute average dispatch prices (in $/MWh), dispatched electricity generation by individual units on a 5-minute interval (in MW), and total demand on a 5-minute interval (in MW). While most data were available on a 5-minute basis, we estimate our regressions on a 30-minute basis because the regulated price settlement period in the NEM is in fact on a 30-minute basis (calculated as the average of six 5-minute intervals). Dispatched electricity generation (in MW) by individual generation units were then allocated into a generation category (eg.: PV, WT, black coal, NG, etc.) based on their dispatch unit code (DUID) to calculate aggregate generation by a specific energy source.

[10] We only take into account utility (or large-scale) PV generation facilities, as they are participating in the NEM, and are hence relevant for the MOE analysis. Distributed, or roof-top PV, which has a significant capacity in Australia, is not included in the MOE analysis explicitly, but it plays an implicit role through reducing the demand in the NEM.

In order to estimate the daily models (Eq. 2), we constructed aggregate daily datasets (generation expressed in MWh), by summing up the MW generating capacity across 5-minute periods in a day and dividing them by 12. Daily prices were calculated as the average daily prices based on forty-eight 30-minute periods. Natural gas price data were only available on a daily basis. For VIC we used the Victorian Wholesale Gas Market data, and for NSW, QLD and SA we sourced gas prices from the Short-Term Trading NG Market for each of those states. All NG price data were in $/GJ format. Data on public holidays were sourced from relevant websites. All data links are found in the Appendix.

4. Results

Results from the estimation of Eq. 1 are presented in Table 2. The results suggest the presence of a merit order effect for both WT and PV generation, in Models 1-5. The coefficient on the wind merit order effect is around -0.011, which indicates that electricity prices are likely to drop with about 11 AUD/MWh with each additional 1 GW of wind dispatched capacity. These results are very robust across different model specifications.

Table 2: Contemporaneous merit order effect of wind and solar generation in Australia 2010-2018.

Dependent variable: Real wholesale electricity price (RRP real) (average over 30 min)	Model 1	Model 2	Model 3	Model 4	Model 5
	coef (se)	coef (se)	coef (se)	coef (se)	coef (se)
(mean) Wind	-0.0111***	-0.0111***	-0.0111***	-0.0113***	-0.0112***
	(0.0012)	(0.0012)	(0.0012)	(0.0013)	(0.0013)
(mean) Solar	-0.0138***	-0.0145***	-0.0139***	-0.0135***	-0.0147***
	(0.0044)	(0.0049)	(0.0044)	(0.0044)	(0.0049)
L.RRP real	0.5426***	0.5422***	0.5426***	0.5425***	0.5421***
	(0.0354)	(0.0354)	(0.0354)	(0.0354)	(0.0354)
L2.RRP real	0.1264***	0.1265***	0.1264***	0.1263***	0.1264***
	(0.0289)	(0.0290)	(0.0289)	(0.0289)	(0.0290)
(mean) Demand	0.0397***	0.0359***	0.0398***	0.0396***	0.0361***
	(0.0022)	(0.0027)	(0.0023)	(0.0022)	(0.0027)
L.Demand	-0.0421***	-0.0328***	-0.0422***	-0.0418***	-0.0331***
	(0.0042)	(0.0045)	(0.0042)	(0.0042)	(0.0046)
L2.Demand	0.0098***	0.0051**	0.0099***	0.0096***	0.0053**
	(0.0022)	(0.0023)	(0.0022)	(0.0022)	(0.0024)
Year	2.6281***	2.6538***	2.6295***	2.6399***	2.6777***
	(0.2560)	(0.2540)	(0.2557)	(0.2587)	(0.2554)
Controls		Intraday	Day-of-week	Month	Intraday, Day-of-week, Month
State fixed effects	yes	yes	yes	yes	yes
R^2	0.413	0.413	0.413	0.413	0.413
Number of observations	537,304	537,304	537,304	537,304	537,304

Note: *** p<0.01, ** p<0.05, * p<0.1. Constants are not reported. Statistically significant controls include "intraday" "day-of-week" and "month". Calculations were carried out with Correia, (2016)'s "reghdfe" command, using HAC errors.

The coefficients on the contemporaneous utility-scale PV merit order effect are close to the reported wind values, although slightly higher around -0.014, indicating a 14 AUD/MWh decrease in wholesale electricity prices with each additional 1 GW of solar utility dispatched capacity.

Our reported MOE national and state coefficients are somewhat larger than previously found in the literature by Wuerzburg et al. (2013), however they are in the line with Woo et al. (2011) or Forrest and MacGill (2013). Due to the highly persistent nature of both electricity demand and prices, all included ARDL lags are significant, as is the time trend. We included the time trend to control for unobservable changes in technology, or market forces driving the change in wholesale prices. Table 3 shows our results for each state individually, with all fixed effects included.

Table 3: State-level contemporaneous merit order effects of wind and solar generation in Australia 2010-2018.

Dependent variable: Real wholesale electricity price (RRP real) (average over 30 min)	NSW	QLD	VIC	SA
	coef/se	coef/se	coef/se	coef/se
(mean) Wind	-0.0028		-0.0053***	-0.0106***
	(0.0019)		(0.0019)	(0.0025)
(mean) Solar	0.0131**	-0.0257*	-0.1231**	-0.1429*
	(0.0058)	(0.0151)	(0.0535)	(0.0845)
L.RRP real	0.8020***	0.4558***	0.6413***	0.5105***
	(0.0968)	(0.0514)	(0.1148)	(0.0617)
L2.RRP real	-0.1105	0.2091***	-0.0694	0.1574***
	(0.0804)	(0.0472)	(0.0786)	(0.0469)
(mean) Demand	0.0423***	0.0451***	0.0416***	0.0491*
	(0.0058)	(0.0108)	(0.0042)	(0.0282)
L.Demand	-0.0487***	0.0026	-0.0324***	0.0981**
	(0.0096)	(0.0197)	(0.0083)	(0.0486)
L2.Demand	0.0156***	-0.0228**	0.0061	-0.1045***
	(0.0047)	(0.0111)	(0.0049)	(0.0248)
Year	2.2719***	-0.1966	4.6330***	4.1529***
	(0.5379)	(0.2355)	(0.8240)	(0.6202)
Controls	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month
R2	0.546	0.389	0.405	0.414
Number of observations	134,254	134,350	134,350	134,350

Note: *** p<0.01, ** p<0.05, * p<0.1 Constants are not reported.

We find that the merit order effect of WT is much lower in Victoria (-0.005) and New South Wales (-0.003) than in South Australia (-0.010). This implicates that the prices are decreasing in Victoria with approximately 5 AUD/MWh, and in NSW with approximately 2.8 AUD/MWh for a GW increase in dispatched capacity, although the NSW coefficient is not significant. The contemporaneous merit order effect of wind generation is the highest in South Australia, which has one of the highest wind generation penetration in the world, with wind generation occasionally exceeding total demand. Monthly wind generation averaged between 40-60% for 2018 in South Australia. The fact that SA has both the highest merit order effect and the largest generating capacity would indicate a growing merit order effect as a function of wind generation capacity. This is in line with Hirth (2013) who note a fall in the value of "wind power from 110% of the average power price to 50–80% as wind penetration increases from zero to 30% of total electricity consumption".

The PV merit order effect seems to be the smallest in Queensland, which has the highest solar irradiance in Australia, and has the largest penetration of rooftop PV generation, but lags behind NSW in utility-scale solar penetration. The coefficients for South Australia and Victoria are very large. Given that PV utility generation has only started in 2018 in both states, we think that these results might be less reliable due to the low number of observations. As noted before, NEM data excludes rooftop PV generation and only presents utility-scale data. To gain more certainty about the magnitude of these coefficients, the coefficients should be re-estimated once sufficient data will be available.

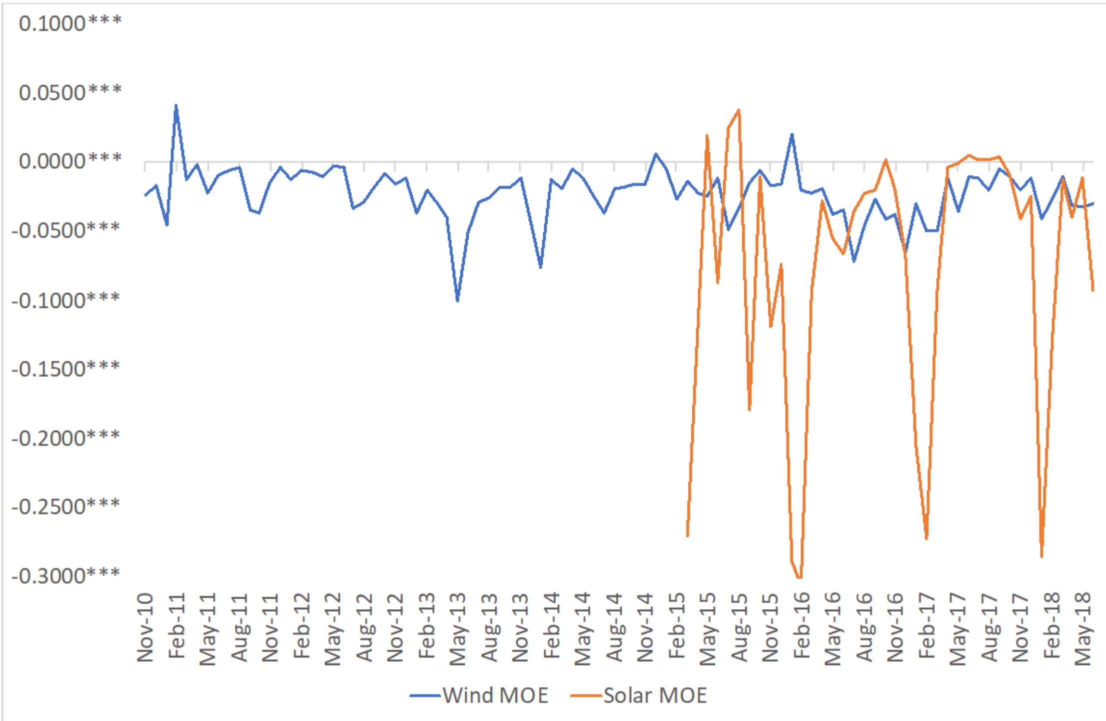

Fig 5. The monthly development of wind and solar MOE in Australia. The contemporaneous merit order effect, based on the 30-minute database was estimated for each month.

Table 4: Annual contemporaneous merit order effects of wind and solar generation in Australia

Dependent variable: Real wholesale electricity price (RRP real) (average over 30 min)	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se
(mean) Wind	-0.0195***	-0.0042	-0.0087***	-0.0214***	-0.0067**	-0.0095***	-0.0323***	-0.0147***	-0.0199***
	(0.0024)	(0.0035)	(0.0030)	(0.0028)	(0.0031)	(0.0030)	(0.0041)	(0.0033)	(0.0041)
(mean) Solar						-0.0072	-0.0494***	-0.0286**	-0.0806***
						(0.0164)	(0.0107)	(0.0115)	(0.0172)
L.RRP real	0.1952	0.8459***	0.7166***	0.3422***	0.4706***	0.3682***	0.3164***	0.5840***	0.7029***
	(0.1194)	(0.0813)	(0.1481)	(0.0538)	(0.1161)	(0.0576)	(0.0686)	(0.0916)	(0.1289)
L2.RRP real	0.0712	-0.0352	-0.1352	0.1487***	0.2124*	0.2720***	0.1523***	0.0620	-0.1166
	(0.0499)	(0.0801)	(0.1043)	(0.0381)	(0.1149)	(0.0808)	(0.0446)	(0.0670)	(0.0773)
(mean) Demand	0.0110***	0.0337***	0.0151***	0.0234***	0.0249***	0.0387***	0.0532***	0.0586***	0.0515***
	(0.0034)	(0.0074)	(0.0032)	(0.0054)	(0.0044)	(0.0106)	(0.0083)	(0.0111)	(0.0096)
L.Demand	-0.0089	-0.0298***	-0.0128**	-0.0162*	-0.0176**	-0.0343**	-0.0402***	-0.0723***	-0.0492**
	(0.0056)	(0.0114)	(0.0059)	(0.0087)	(0.0080)	(0.0152)	(0.0146)	(0.0207)	(0.0191)
L2.Demand	-0.0006	0.0053	0.0027	-0.0000	0.0008	0.0038	-0.0031	0.0318***	0.0108
	(0.0041)	(0.0062)	(0.0032)	(0.0046)	(0.0050)	(0.0073)	(0.0071)	(0.0111)	(0.0116)
Controls	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month	Intraday, Day-of-week, Month
State fixed effects	yes	yes	yes	yes	yes	yes	yes	yes	yes
R2	0.079	0.678	0.443	0.204	0.404	0.327	0.210	0.419	0.427
Number of observations	11,700	70,080	70,272	70,080	70,080	70,080	70,176	70,080	34,756

note: *** p<0.01, ** p<0.05, * p<0.1. Constants are not reported. Statistically significant controls include "intraday" "day-of-week" and "month". Calculations were carried out with Correia, (2016)'s "reghdfe" command, using HAC errors.

An interesting question relates to the change in the merit order effect over longer periods of time. The major driving factor behind such change is likely to be the change in the PV and WT generation capacity over time. We present the annually estimated contemporaneous merit order effects for each year from 2010 to 2018 in Table 4. We also show the development of the contemporaneous merit order effect, estimated for each month for the past 8 years in Figure 5. We can see that the impact of wind power on electricity prices appears to be mildly fluctuating throughout the entire year. The merit order effect of solar power however seems to be strongly negative during summer months (Jan-Feb), while falling back towards zero or even positive values during winter (July-Aug). We show the impact of dispatched capacity on the magnitude of the merit order effect in Table 5.

Table 5: Merit order effect as a function of dispatched capacity in the Australian NEM 2010-2018

Dependent variable:	Wind MOE coef/se	Solar MOE coef/se
Average Dispatched Wind Capacity	-0.0000152*	0.0001227**
	(0.0000086)	(0.0000519)
Average Dispatched Solar Capacity	0.0000022	-0.0001450
	(0.0000608)	(0.0005335)
R2	0.057	0.110
Number of observations	92	40

Note: *** p<0.01, ** p<0.05, * p<0.1 Constants are not reported. The regression was estimated after extracting the contemporaneous merit order effect from Eq1 for each month between December 2010-June 2018. We regressed the monthly average dispatched NEM capacity on the merit order coefficients.

We find that while increases in dispatched wind capacity tend to be associated with a more negative wind merit order effect (therefore increasing the impact of wind generation on price as capacity increases), we do not find the impact of solar dispatched capacity on the solar merit order significant. This might be due to the shortness of the data on utility-scale PV. We do find however that increases in wind dispatched capacity tend to be associated with a lower solar merit order effect. This could be the case if wind and solar generation were complimentary to each other, thus during peak wind generation months, solar generation would be comparatively lower.

While the contemporaneous merit order effect is known to be very large, the daily merit order effect is expected to be lower. Table 6 presents the daily merit order effect for Australia.

Table 6: Daily merit order effect of wind and solar generation in Australia 2010-2018.

Dependent variable: Real wholesale electricity price (RRP) (average over 24 hours)	**Model 1**	**Model 2**	**Model 3**	**Model 4**
	coef/se	coef/se	coef/se	coef/se
Wind	-0.0010***	-0.0009***	-0.0010***	-0.0009***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Solar	-0.0027*	-0.0028*	-0.0031**	-0.0032**
	(0.0015)	(0.0015)	(0.0015)	(0.0015)
L.RRP real	0.3390***	0.3379***	0.3362***	0.3352***
	(0.0834)	(0.0831)	(0.0831)	(0.0827)
L2.RRP real	0.0309	0.0320	0.0280	0.0290
	(0.0294)	(0.0293)	(0.0292)	(0.0291)
Demand	0.0010***	0.0013***	0.0010***	0.0013***
	(0.0001)	(0.0002)	(0.0001)	(0.0002)
L.Demand	-0.0005***	-0.0006***	-0.0005***	-0.0006***
	(0.0001)	(0.0002)	(0.0001)	(0.0002)
L2.Demand	-0.0001	-0.0003**	-0.0001	-0.0002**
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
GasPrice real	4.8604***	4.9010***	5.1546***	5.1876***
	(0.6539)	(0.6553)	(0.6539)	(0.6546)
Year	2.1696***	2.1040***	2.1129***	2.0517***
	(0.3954)	(0.3863)	(0.4210)	(0.4111)
Controls		Day-of-week	Month	Day-of-week, Month
State fixed effects	yes	yes	yes	Yes
R2	0.270	0.273	0.272	0.275
Number of observations	11,185	11,185	11,185	11,185

Note: *** p<0.01, ** p<0.05, * p<0.1 Constants are not reported. Statistically significant controls include "intraday" "day-of-week" and "month". Calculations were carried out with Correia, (2016)'s "reghdfe" command, using HAC errors.

We examine the effect of the total daily WT and PV electricity generation on the average daily prices. Our results show that one GWh increase in total daily generation would be associated with approximately 1 AUD/MWh price decrease in the daily average prices. Similarly, one GWh increase in solar generation during a day is associated with 2.7 AUD/MWh decrease in the wholesale electricity prices. Of special interest is the coefficient on the NG prices. We find NG prices to be an important driver of daily wholesale prices. This is in line with the findings of Borenstein and Bushnell (2015) and Csereklyei and Stern (2018) in the United States, where gas prices tended to be the key driver of wholesale electricity prices in states with liberalized (restructured) wholesale electricity markets.

In case of the Australian market, the annual average prices for natural gas increased from approximately to 3AUD/GJ to 8 AUD/GJ from 2011 to 2017. Given the estimates of our model, this increase is expected to account for approximately 25

AUD/MWh increase in wholesale prices. At the same time the merit order estimates suggest that 1 GW additional dispatched wind capacity results in approximately 11 AUD/MWh reduction in prices. In 2017, the average monthly dispatched WT capacity in the NEM was around 1.2 GW. This would indicate an expected decrease in wholesale prices by about 13.2 AUD/MWh. Average monthly solar dispatched capacity in 2017 moved around 0.07 GW. As the solar MOE was approximated with 14AUD/MWh with each additional GW capacity, this would indicate a total decrease of about 1 AUD/MWh. This implies that the joint effect of the WT and PV merit order effect is still lower than the increase in electricity prices attributed to higher NG prices. The average wholesale electricity prices have increased from 36 AUD/MWh (2011) to 89 AUD/MWh by 2017. This implies that other factors, including market-behaviour were at work as well, contributing to the substantial increase in wholesale electricity prices.

Table 7: State-level daily merit order effects of wind and solar generation in Australia 2010-2018.

Dependent variable: Real wholesale electricity price (RRP) (average over 24 hours)	NSW	QLD	VIC	SA
	coef/se	coef/se	coef/se	coef/se
Wind	-0.0002		-0.0003**	-0.0009***
	(0.0002)		(0.0001)	(0.0003)
Solar	-0.0015	-0.0236***	-0.0037	-0.0377
	(0.0013)	(0.0066)	(0.0130)	(0.0234)
L.RRP real	0.5980***	0.2977**	0.3810***	0.2183**
	(0.2053)	(0.1172)	(0.0760)	(0.1074)
L2.RRP real	-0.1102	0.0389	0.0600	0.0121
	(0.1069)	(0.0398)	(0.0630)	(0.0315)
Demand	0.0011***	0.0043***	0.0015***	0.0054***
	(0.0003)	(0.0010)	(0.0003)	(0.0017)
L.Demand	-0.0006***	-0.0026***	-0.0007***	-0.0019**
	(0.0002)	(0.0008)	(0.0002)	(0.0009)
L2.Demand	-0.0001	-0.0004	-0.0001	-0.0004
	(0.0001)	(0.0003)	(0.0001)	(0.0004)
GasPrice real	2.8421***	4.7612***	3.4125***	10.0150***
	(0.9971)	(1.0621)	(0.5145)	(1.8020)
Year	2.0900***	-0.5112	3.5974***	3.0428***
	(0.6625)	(0.6960)	(0.6644)	(1.0427)
Controls	Day-of-week, Month	Day-of-week, Month	Day-of-week, Month	Day-of-week, Month
R2	0.452	0.268	0.476	0.283
Number of observations	2,795	2,797	2,796	2,797

Note: *** p<0.01, ** p<0.05, *p<0.1 Constants are not reported.

Table 7 presents state-level daily merit order effects. The daily merit order effect of WT is only significant for SA and VIC. In South Australia, one GWh increase in WT generation in a given day would decrease the average daily prices with approximately 0.9 AUD/MWh, while this number is 0.3 AUD/MWh in Victoria. The daily PV merit order effect is only significant for Queensland, where a GWh increase in daily total generation would result in approximately 23.6 AUD/MWh decrease in the prices. NG prices are significant, but hikes in NG prices seem to impact on electricity prices in South Australia the most, which has a relatively high proportion of NG generation both in terms of baseload and peaking load. The time trend is positive for all states but Queensland, showing a general trend that increases in prices can also be attributed to changes in regulatory environment, market and technological changes, and to weather and climate patterns.

5. Conclusions and Policy Implications

Electricity prices are among the most important policy issues currently in Australia and represent a critical component of the energy and climate change policy discussions. Several attempts to move forward on energy and climate change policies have been stymied due to concerns about possible further electricity price increases. Within this policy debate in Australia, renewable electricity generation is seen as a fundamental factor influencing electricity prices. In light of the coincidence between increasing penetration of WT and PV generation in Australia and increasing wholesale and retail electricity prices, there is a widely held belief that wholesale electricity price increases are related to increased penetration of renewables.

In this paper we estimated the effect that the increased penetration of renewables has had on wholesale electricity prices in Australia's NEM. We find evidence for the existence of both wind and solar merit order effect, meaning that additional wind and solar generation resulted in reductions in wholesale electricity prices. We can conclude that under a counterfactual of a lower penetration of these renewable generation sources than what has actually been the case, wholesale electricity prices in Australia would have been higher than they actually were.

We also find that the moderating effect that wind generation has on electricity prices has been increasing as a function of average dispatched capacity. On the other hand, increases in the dispatched capacity of wind appeared to lower the merit order effect of utility-scale solar PV. Given that the trends clearly point to further expansion of both utility-scale PV and WT, we can expect that the moderating effect of renewables on electricity prices is likely to continue. Long-term predictions are difficult to make, especially because the long-term effects of increased renewable electricity generation on electricity systems are much less understood than the short-term effects. We also find that the actual increases in wholesale prices in the Australian NEM can be attributed to a great extent to increases in the price of natural gas. The effect of NG price increases was found to outweigh the moderating effect of the renewable generation on electricity prices.

Our findings have important policy implications. One implication is that energy policy in Australia should not withdraw support for WT and PV electricity generation based on the notion that it leads to higher wholesale electricity prices. On the contrary, energy policy that supports further penetration of renewables is likely to create effects that will decrease wholesale electricity prices. In addition, energy policy that supports renewables is in line with medium and longer-term aspirations of reducing greenhouse gas emissions, such as the aim of zero net emissions by 2050 (OEH, 2015), or Australia's 2030 climate change targets (Commonwealth of Australia, 2019).

Another implication is that energy policy should consider its reliance on peak-loader electricity generation based on NG, as high NG prices directly lead to higher wholesale electricity prices. While the reliance on peak-loaders is known to increase with the penetration of renewables, alternative system stabilising solutions, such as the use of large-scale batteries should be considered.

Further research is required to better understand the role of climate cycles, as well as the long-term effects of renewable electricity generation on electricity prices. Overall, the evidence gathered in Australia indicates that increased penetration of renewables has been beneficial, not only in terms of moderating greenhouse gas emissions, but also in terms of the effects on electricity wholesale prices. This suggests that energy policy supportive of renewable electricity generation is the way to go for Australia.

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Appendix 1:

Data Sources:

- 5-min SCADA (individual unit) generation data:

http://nemweb.com.au/Data_Archive/Wholesale_Electricity/MMSDM/2018/MMSDM_2018_01/MMSDM_Historical_Data_SQLLoader/DATA/PUBLIC_DVD_DISPATCH_UNIT_SCADA_201801010000.zip. The generation data is in column 'G' titled 'SCADAVALUE'. Solar generation numbers reported by the AMEO in NSW on 16 November 2016 and 18 November 2016, were clearly erroneous. We have set the solar generation values on these two days for NSW as missing.

- Electricity price at a 5-minute interval:

http://nemweb.com.au/Data_Archive/Wholesale_Electricity/MMSDM/2018/MMSDM_2018_01/MMSDM_Historical_Data_SQLLoader/DATA/PUBLIC_DVD_DISPATCHPRICE_201801010000.zip

- DUID ID:

NEM Registration list: https://www.aemo.com.au/-/media/Files/Electricity/NEM/Participant_Information/NEM-Registration-and-Exemption-List.xls. The information is in Worksheet 4 ' Generators and Scheduled Loads'

- Gas prices

Gas price data for VIC: http://aemo.com.au/Gas/Declared-Wholesale-Gas-Market-DWGM/Data/VIC-Wholesale-Price-and-Withdrawals . Colum "F' 'price_value'. Unit: $/GJ

Gas price for NSW, QLD and SA: https://www.aemo.com.au/Gas/Short-Term-Trading-Market-STTM
And https://protect-au.mimecast.com/s/9KToC0YZWVFK5xnlfwvTIZ?domain=google.com
Column 'C' for each city (separate tab) 'City abbreviation expost_price'. Unit: $/GJ

- Demand

Demand was sourced from:
http://nemweb.com.au/Data_Archive/Wholesale_Electricity/MMSDM/2018/MMSDM_2018_01/MMSDM_Historical_Data_SQLLoader/DATA/PUBLIC_DVD_TRADINGREGIONSUM_201801010000.zip
Column I, titled 'TOTALDEMAND". Units are all in MW for the given time period.