Australian National University

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Institute for Climate, Energy & Disaster Solutions

Australian Energy Emissions Monitor

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Australian Energy Emissions Monitor

Contents

Key Points

- As Australia emerges from the disruptions of lockdowns, the transition of the National Electricity Market towards a low emission future continues. Conversely, there remains no evidence of any significant transition in either the petroleum or gas systems, with emissions on trend to return to pre-pandemic levels, if not higher.
- In the year to November 2021, variable renewable (wind and solar) generation supplied 25% of all electricity generated in the NEM. If hydro is included, the renewable share increases to 32%.
- The highest monthly share of renewable generation to date occurred in October 2021, with 28% wind and solar and 36% total renewables.
- During the three days 25 to 27 November 2021, the South Australian electricity system was supplied almost entirely by wind and solar generation. During short periods, when additional supply was required, gas generation and imports from Victoria supplied 8% of total demand, but exports of excess wind and solar generation totalled 16% of generation over the same three days.
- The level of spot wholesale electricity prices, when averaged across the whole nine days from 19 to 28 November in South Australia, with no coal generation and 79% variable renewable generation, was half or less than the corresponding average level of wholesale prices in New South Wales and Queensland, where coal fuelled nearly three quarters of total electricity generated over the same period.

Introduction to the first issue

Welcome to the first issue of the *Australian Energy Emissions Monitor*, which will be a bi-monthly publication of the ANU Institute for Climate, Energy and Disaster Solutions, providing timely analysis of most recent trends in energy related carbon dioxide emissions. Although a new publication for the ANU, it is the successor to a publication which has been published regularly, under two different titles and auspices, for over twelve years. The publication is intended as a service to Australia's energy community.

The aim of the *Monitor* is to estimate and report on Australia's energy combustion emissions as soon as reasonably possible after data sufficient to do so becomes publicly available. This timing has consistently been 6 to 8 weeks after the last day of the month to which the emissions estimates relate. Energy combustion remains by far the largest contributor to Australia's total greenhouse gas emissions (72% in 2020) and is the main opportunity to rapidly reduce emissions. Minimising the lag between when emissions occur and when they are reported allows faster and more complete understanding of how Australia's emissions are tracking, and what changes are needed to achieve faster emissions reductions.

The *Monitor* covers around 80% of Australia's energy combustion emissions, with data on the remaining 20% of energy related emissions not available within the window of a 6 to 8 week lag, and some not publicly available at all. It has been practice for some years to provide, in the first issue published after each annual National Greenhouse Gas Inventory Report (NGGI) has been released, to include a comparison and reconciliation; this practice will continue. More detailed information on which emissions are reported by the *Monitor* and which are not, and on data sources and methodology, are in the Appendix.

Every issue of the *Monitor* will adopt a broadly similar format. Presentation will be structured around consumption, and emissions arising from consumption, of each of the three main energy sources or fuels used by Australian energy consumers: electricity, natural gas, and petroleum products. Most data will be presented in the form of graphs, most of which will show trends over time. All underlying data will be in the form of monthly totals, and many of the graphs will show moving annual totals for the variables depicted, this being the clearest and simplest way to eliminate regular seasonal variations from long term trends. The underlying data will be provided online alongside the reports. Some graphs will be specifically intended to retain seasonal variations, and to do so will show average daily values for each month of the variable depicted. Apart from reporting separately, and in combination, monthly energy consumption and emissions from generation of electricity and use of petroleum products and gas, most issues will also include discussion of one or more special subjects, mostly chosen on the basis of topicality at the time.

The special focus in this issue is the spectacular transformation in electricity generation in South Australia, and how the security of the state's electricity supply system is being managed through that transformation.

Wind and solar generation always make their largest contribution, as a share of total NEM generation, during the spring months of September, October and November. On the demand side, milder weather reduces electricity demanded for space heating or cooling in both residential and commercial buildings, and hence total electricity demand. On the supply side, September is almost always one of the windiest months of the year, while in October and November, as average wind speed falls away, lengthening days and higher irradiation angles result in rapidly increasing daily solar generation. The resultant effects on the electricity supply system were seen most dramatically in South Australia during the second half of November. They could well be a foretaste of what the whole NEM might be like ten years hence, if present trends continue.

Hugh Saddler (author and analyst) and Frank Jotzo (Head of Energy, ICEDS)

Trends in energy consumption and emissions

Australia's energy combustion emissions have been decreasing over the past four years but only because of the steady transition from coal fired generation to wind and solar in the NEM.

Figure 1 shows monthly moving annual energy combustion emissions, as estimated by the *Monitor*, since the year 2010-11, and Figure 2 shows the changes from 2010-11 to the year ending September 2021. Note that the significant increase in petroleum product emissions since 2016 may be, at least in part, an artefact caused by under-reporting of sales by the petroleum distribution and marketing companies prior to that year. This under-reporting was corrected by amendments to the legislation mandating monthly reporting of petroleum product sales. That said, the data show that up to March 2020, when the first lockdowns were imposed, consumption of petroleum products, and resultant emissions, were staying roughly constant, as was consumption of gas. Reductions in total emissions were being driven entirely by steadily falling emissions from electricity generation.

Lockdowns caused a sharp reduction in consumption of fuel use by cars and light commercial vehicles and also by aviation. This started to be reversed in March 2021, but the increase almost stopped again in July, when lockdowns were reimposed in NSW and Victoria.

Figure 1: Moving annual energy combustion emissions, 2011-21

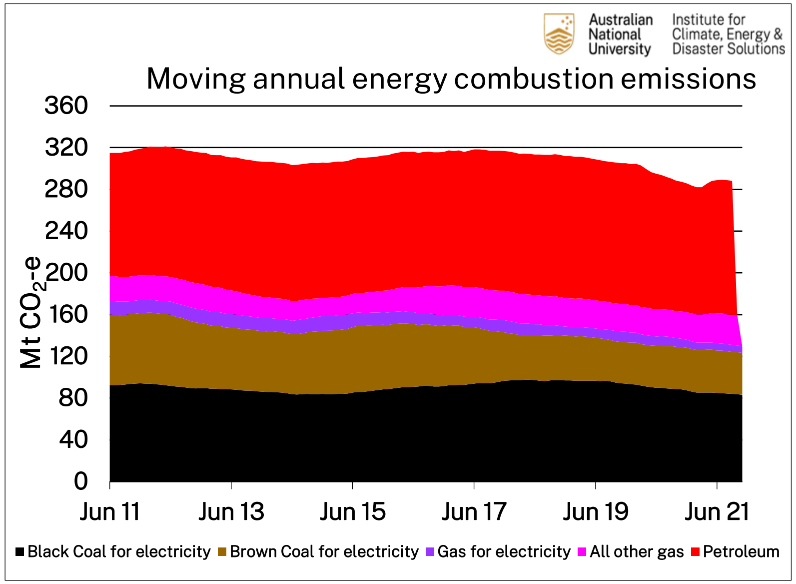
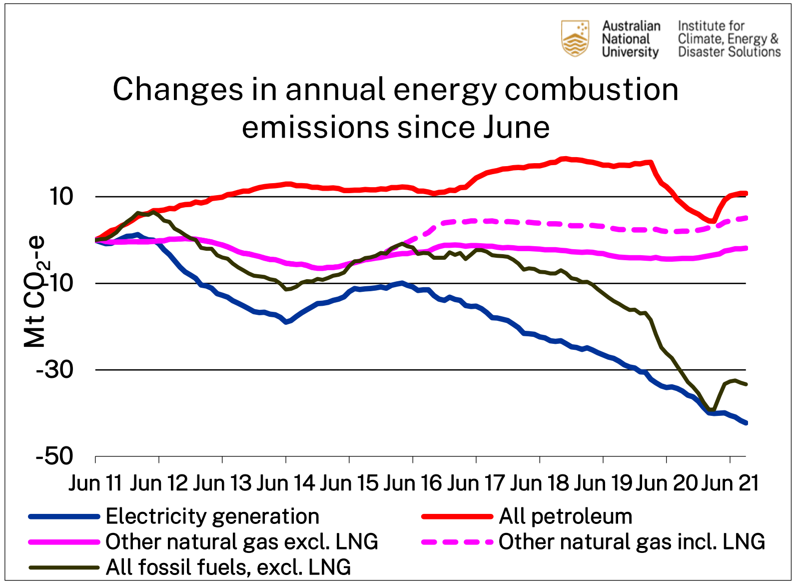


Figure 2: Changes in moving annual energy combustion emissions, 2011-21



Consumption of petroleum fuels and natural gas is making no contribution to Australia's emissions reduction task.

Overall, the contrasts between trends in electricity, petroleum and gas show that, while the electricity system is definitely in the midst of transition, the petroleum and gas systems, just as definitely, show no signs of even starting on transition. It is therefore wrong, and misleading, to refer to an energy transition in Australia, when what is meant is an electricity system transition only.

Electricity generation, consumption and emissions in the NEM

Figure 3 shows the absolute changes in sent out generation in the NEM. Sent out generation means the quantity of electricity leaving each power station and entering the transmission system. It differs from what is termed as generated generation, which is larger, by the quantity of electricity used within a power station, termed auxiliary load. Auxiliary load powers equipment essential to the operation of a thermal, particularly a coal-fired, power station, such as conveyors, pumps and fans.

Figure 4 shows the same data, but expressed as shares of total sent out generation. In this graph electricity supplied by wind, grid solar and rooftop solar has been combined in a single number, as variable renewable generation. Note that the term variable is preferred to intermittent, although both have the same meaning in this context. The term intermittent has been weaponised to carry strong pejorative implications through its use by culture war opponents of the electricity system transition. NEM electricity generation emissions reached their historic maximum level in the year to September 2008. Nationally, electricity emissions peaked about a year later (the year 2008-09 in the NGGI), because the transition in W.A. and the N.T lags the transition in the NEM.

Figure 3: Annual electricity generation in the NEM, 2008-21

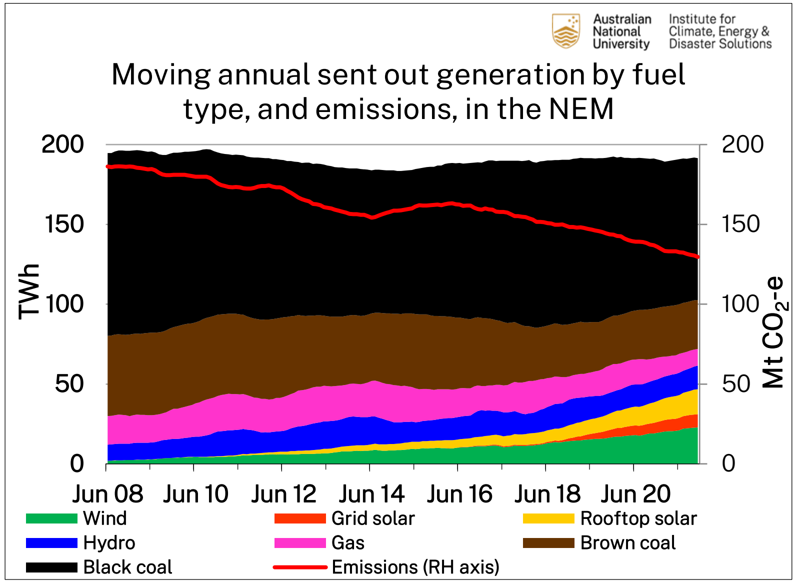
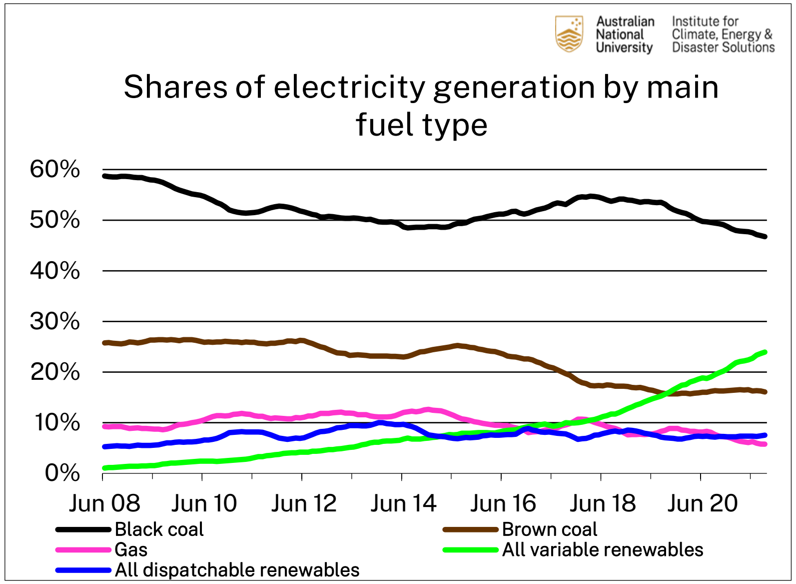


Figure 4: Changes in shares of sent out generation, 2008-21



It can be seen that variable renewable generation is now supplying almost one quarter (more precisely, 24.8%) of electricity supplied in the NEM in the year to November 2021. When hydro is also included, the total renewable generation rises to nearly one third (32.2%).

Figure 5 shows how these changes in the generation mix and in the total demand for electricity have combined to result in falling emissions and emissions intensity from electricity generation over the past thirteen years. The emissions intensity measure used is total emissions divided by the sum of total generation sent out by grid generators plus total electricity generated by rooftop solar.

Figure 4 shows that the fall in emissions and in emissions intensity over this period can be separated into two phases. During the first phase, up to 2015, the main factors were falling consumption, combined with the closure of a number of old coal-fired power stations. During the years 2013 to 2014, this was accelerated, and then reversed, by the introduction and subsequent removal of the carbon price. Since 2015, the main driver has been the steady growth in the shares of grid solar and wind generation, plus rooftop solar generation, and the off-setting reduction in coal generation, as shown in Figures 3 and 4.

Figure 5: Relative changes in generation, emissions and emissions intensity, 2008-21

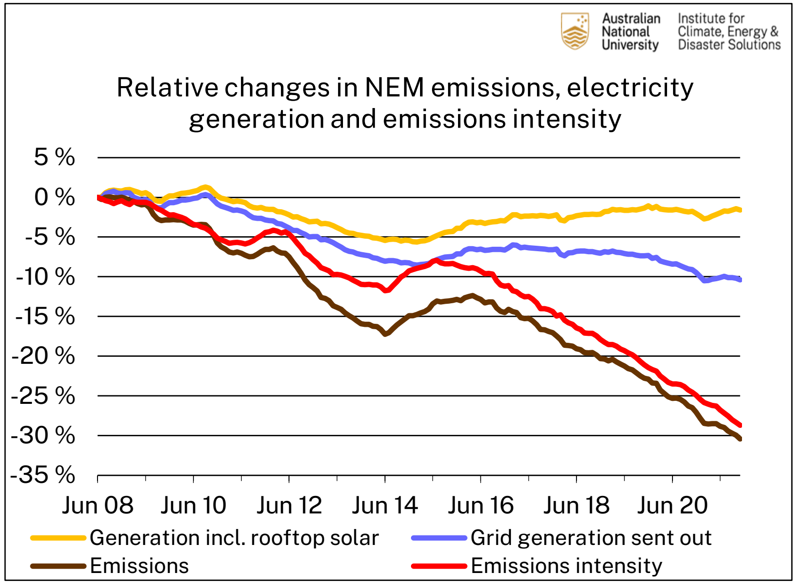
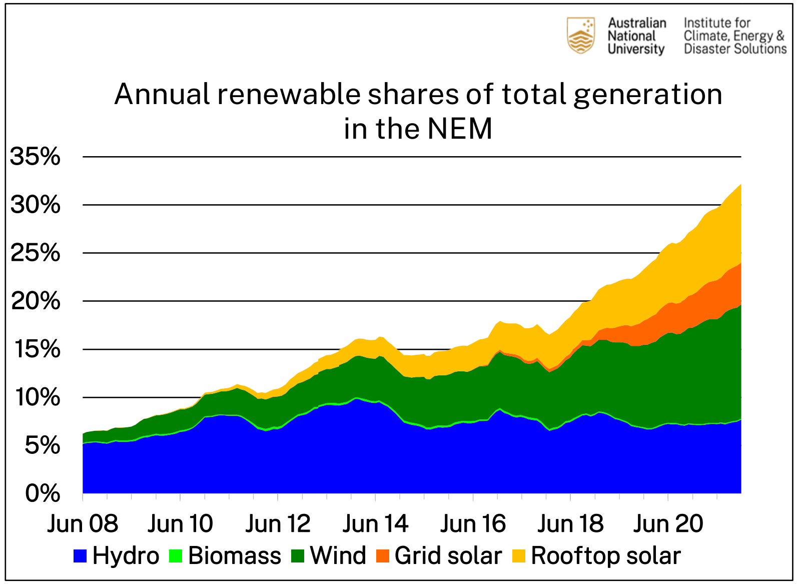


Figure 6 shows annual shares of renewable generation in the NEM. It shows that the growth in wind and solar generation in the NEM has gone through three distinct phases since 2008. The first phase shows steady growth of wind generation, almost all of which was in South Australia and Victoria, and the beginnings of rooftop solar. The change in government in 2013 brought policy uncertainty, accompanied by much hostility to wind and solar generation. The effect on new investment in renewable generation is quite clear. Significantly, the graph shows the impact of such events is quite long lasting, because of the long lead times from conception to commissioning of new projects. Strong growth did not re-emerge until 2019, and is now continuing.

Figure 6: Moving annual shares of renewable generation in the NEM, 2008-21



Figures 7 and 8 show average daily variable, i.e. wind and solar, generation by month (using average daily figures removes the effect of different numbers of days in the month). The sequence of the "stack" differs between the two graphs, in order to show more clearly the marked and consistent seasonality of solar generation. Wind generation is less consistently seasonal, but is generally at its highest from July to October. The combined seasonality effect is that total variable generation usually reaches its maxima in spring and early summer.

At the other extreme, the period from May to early July is when average wind speeds tend to be at their lowest, at least in southern Australia, and solar radiation reaches its annual minimum, in the second half of June. This period is therefore when total variable renewable generation is at its lowest. The combination of these seasonal effects on generation with colder weather means that these are the months when variable renewable generators contribute on average the smallest monthly share of total electricity demand.

Experience in the NEM over the past few months also shows that it is during this early winter period that so called *dunkelflaute* ("dark calm") conditions are most likely to extend over several days. It is under these conditions that either so-called deep or seasonal storage, or large contributions from peaking gas generation, or an alternative with similar characteristics, will be needed as the transit to renewable generation continues. However, it is important to understand that the total duration of such events is not large, so that they will not require extensive use of gas generation, or a lower emission alternative, let alone coal fired generation.

Figure 7: Monthly electricity supplied by variable renewable generators, 2015-21

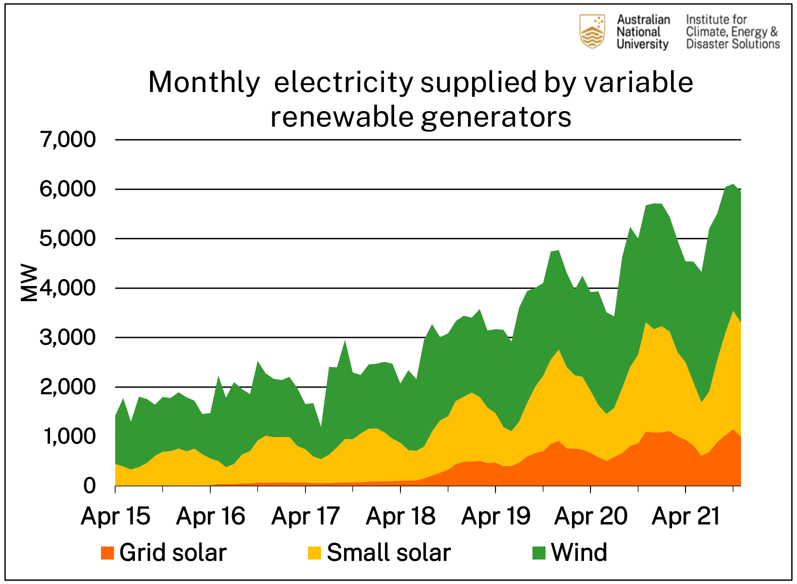


Figure 8: Monthly shares of variable renewable generation, 2015-21

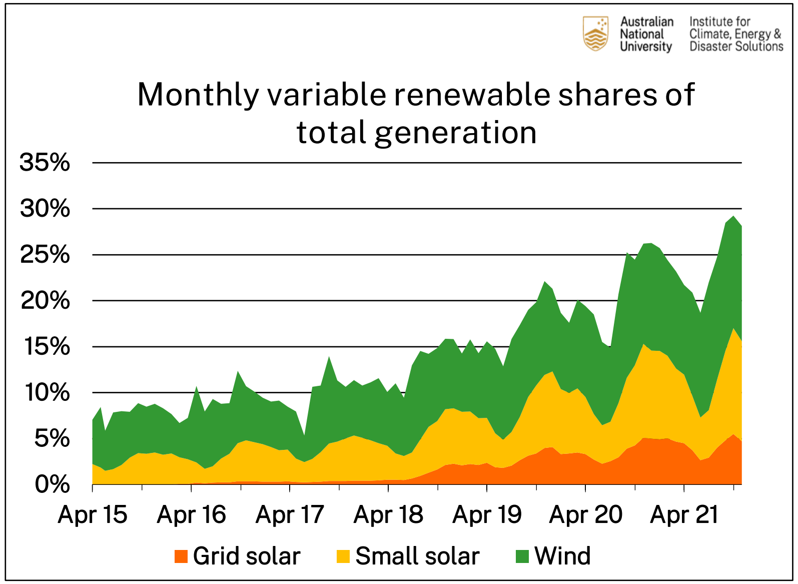
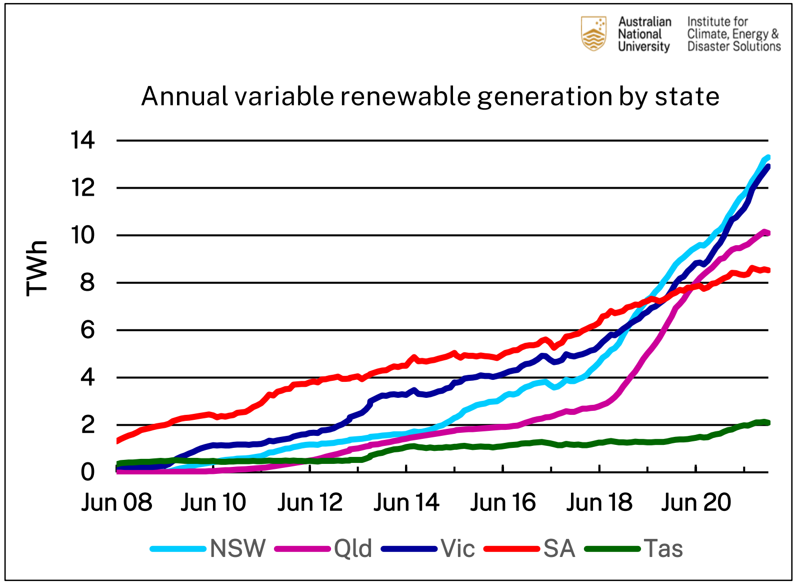
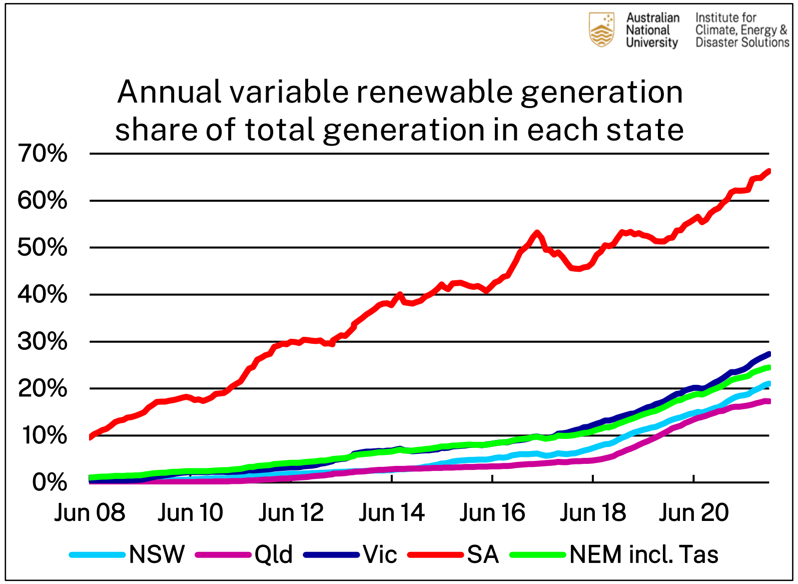


Figure 9: Moving annual variable renewable generation in each state, 2008-21



Finally, in this overview of the electricity sector, Figures 9 and 10 show respectively moving annual total variable renewable generation in each state, and variable renewable generation as a share of total generation. It is interesting to note that, over the most of the past three or so years, wind and solar generation have been growing at about the same rate as shares of total generation in all four mainland states, though in absolute terms the growth has been lower in South Australia, where total generation and consumption of electricity is much smaller. However, growth in Queensland seems now to be falling away, which is not a good performance, given that Queensland has consistently lagged all the other states in its uptake of wind and solar generation.

Figure 10: Moving annual variable renewable generation share of total in each state, 2008-21



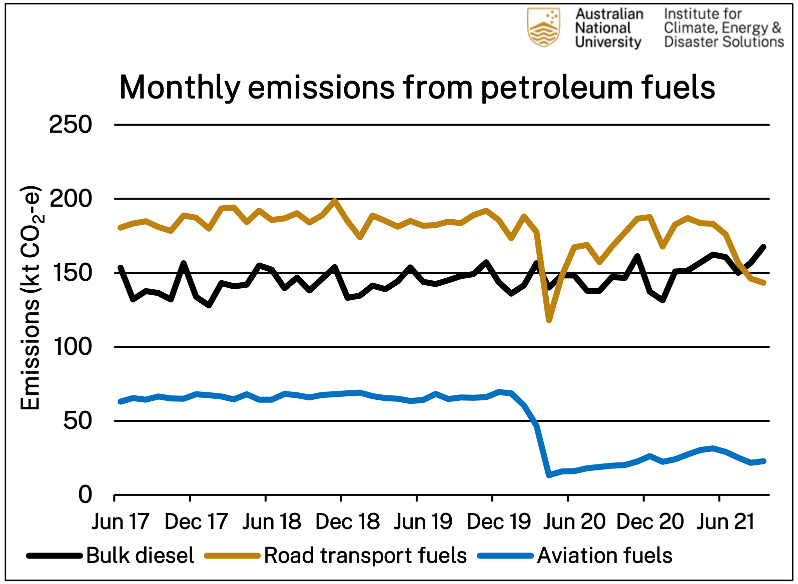
Recent trends in petroleum emissions

Diesel and petrol (usually termed mogas by the industry) account for the great majority of petroleum fuels used in Australia. Jet fuel (avtur) is the next largest fuel type. Figure 11 shows emissions arising from use of the volumes of these petroleum fuels sold throughout Australia each month over the past four years, again normalised by the number of days in the month. The data are presented in a way that, very roughly, but to the extent that the data allow, assigns fuels to uses. The key data source, *Australian Petroleum Statistics*, reports monthly sales of petrol and diesel split into retail sales and all other sales. For petrol, retail sales account for the great majority of all sales and, because petrol has few other uses except for use in small machinery such as portable generators, lawnmowers, and outboard motors, it is assumed that both retail and bulk sales are used in road transport. Diesel fuel, on the other hand, is used in an extremely wide variety of applications, many not related to road transport. The assumption used is that retail sales are all for road transport, and other, i.e. bulk sales, are not, though in fact some road transport fleet operators, such as bus companies, certainly acquire their diesel fuel in bulk. Aviation fuels include fuel used for both domestic and international aviation.

The first characteristic of the data is that, prior to the onset of pandemic lockdowns, the consumption trend was almost flat, with a slight increasing trend for bulk diesel. This observation is of course consistent with the data in Figure 1. In March 2020, road transport fuel consumption fell sharply, and since them has followed the ups and downs of the various lockdowns. Note that these are national data, and that the effect of lockdowns has been much deeper and more extended in New South Wales and Victoria than in other states. That is why the fall in consumption may appear smaller than expected. The next issue of *Australian Energy Emissions Monitor*, in February 2021, will include state by state trends in monthly emissions from petroleum fuels, and also from electricity and gas. These trends show clear state by state differences.

The impact on consumption of aviation fuels is very clear and just as would be expected, given the almost complete cessation of passenger flights during the early months of the pandemic.

Figure 11: Average daily emissions by month from main categories of petroleum fuels, 2017-21



By contrast, there is no evidence of any impact of lockdowns on bulk diesel consumption. Major consumers of bulk diesel include mining, agriculture, heavy road freight vehicles and buses, rail transport, and remote area electricity generation. These data confirm what has been reported, on the basis of many other economic activity data, that none of these activities have experienced a significant downturn.

Overall, these data are consistent with the observation in the opening section of this *Monitor*: that no energy transition is occurring in the use of petroleum fuels.

Special feature: the South Australian electricity system during November 2021

South Australia has a much larger share of variable renewable generation than any other state, as seen in Figure 10. This applies to both grid connected wind and solar farms and to rooftop (small) solar generation, for which the annual share in South Australia in the year to November was 17%, compared with 10% in Queensland, the next highest state. (The South West Interconnected System in Western Australia may be close to South Australia, but detailed data are more difficult to obtain.)

During the last two weeks of November, most of south east Australia experienced prolonged windy weather, accompanied in South Australia for much of the period by long periods of sunny weather and relatively mild temperatures. It is under these conditions that records for supply from variable renewable generators are usually recorded, and that was certainly the case this year. A few months ago, ElectraNet, the transmission network service provider for South Australia, completed commissioning its four synchronous condensers and was approved by AEMO to integrate them into the operation of the state's grid. These machines supply no energy, but do provide inertia to the electricity system, while using very little energy. Their commissioning has enabled AEMO, with the experience it has gained while operating the South Australian grid with high levels of wind and solar generation over the last two or so years, to change its operating requirements for the South Australian grid. Previously, AEMO required quite large minimum levels of gas fired generation to be on-line at all times to provide system security. This often meant that, under windy and/or sunny conditions, wind and/or solar generators were required to curtail their output to avoid generation in South Australia exceeding the combined demand for electricity in the state and the export capacity available through the interconnectors to Victoria. AEMO no longer requires more than a very small amount of gas fired generation to be on-line at all times, thereby enabling wind and solar generators to supply at their maximum available capacity. The overall effects of all these changes are shown in Figures 12 and 13.

The period covered is from Friday 19 November to Sunday 28 November. The graphs all show power, in MW, averaged over 30 minute intervals. The term grid demand is, essentially, electricity supplied by generators connected to the transmission system. It includes supply from what are called, in AEMO's electricity market terminology, scheduled and semi-scheduled generation, and also supply from a relatively small number of older windfarms classified as non-scheduled. A minimum level of supply from these generators, taken together, is required to keep the grid functioning at all times, and in particular to keep frequency stable at 50 cycles per second.

When there is a high level of supply from rooftop solar, the need for supply from the grid is reduced, and grid generation is reduced to low levels. The graphs show that is what happened in South Australia during late November, particularly on Days 2 to 4 (Saturday 20, Sunday 21 and Monday 22 November) and on Days 7 to 10 (25, 26, 27, and 28 November). Total demand, as shown in the graphs, means electricity supplied from the grid, plus electricity supplied from rooftop solar installations.

Figure 12 shows that on each of the days listed above, gas generation was allowed to fall to extremely low levels in the middle of the day, and on several days those low levels persisted for much longer. For the whole of Friday 25 November and most of Saturday 26, gas generation was less than 100 MW and electricity consumers were being supplied almost entirely by wind and solar generation (wind only, of course, overnight). On all nine days there were at least some periods when total generation, even with gas at very low levels, exceeded demand, meaning that electricity was exported to Victoria. On the other hand, electricity was imported from Victoria overnight on all but one day, this being a lower cost option than using local gas generation.

Figure 12: Generation and demand in South Australia

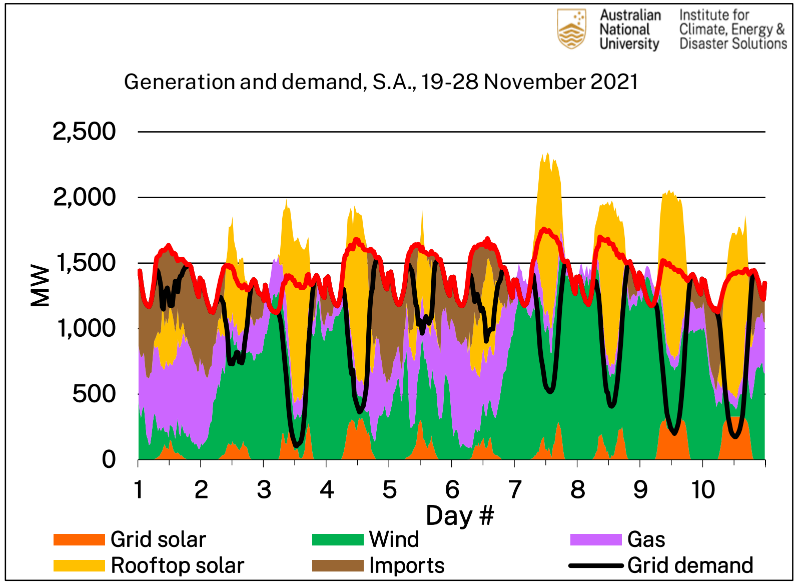


Figure 13: Rooftop solar supply and spot price in South Australia

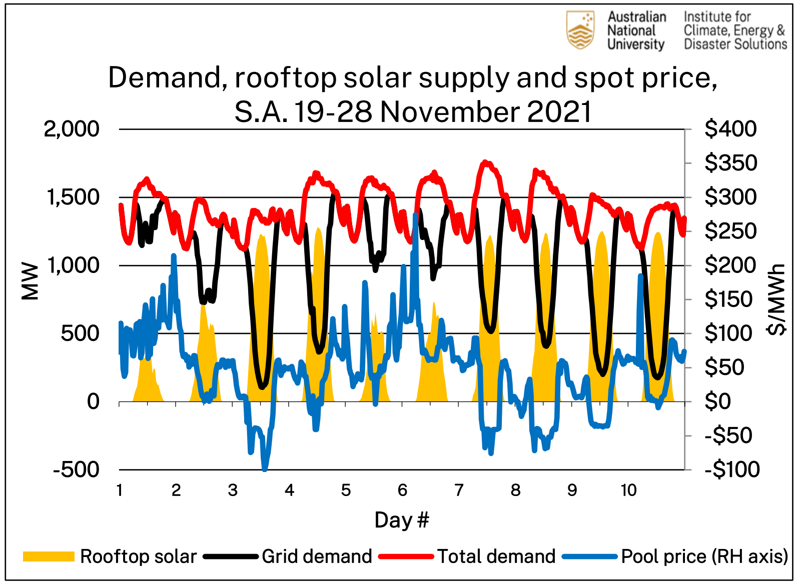


Figure 14: Generation shares and average spot prices in each NEM region

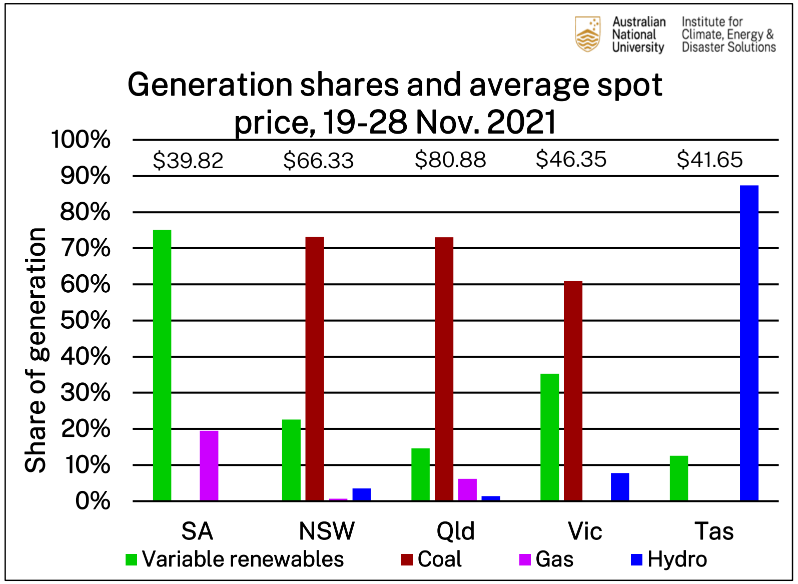


Figure 13 shows very considerable price volatility, with periods of negative prices in the middle of five of the ten days, and high overnight prices on four days. The volume weighted average spot price for the entire nine days was $39.82 per MWh. This average was calculated taking account of the volumes of imports from and exports to Victoria during the nine days, over the two interconnectors which link the transmission networks in the two states. Figure 14 compares the results of calculating similar volume weighted average prices in each of the other four state regions of the NEM.

Obviously, prices were much lower in the three southern states than in New South Wales and Queensland. This one set of calculations cannot be said to demonstrate that high shares of solar and wind generation will automatically deliver low wholesale prices to electricity consumers. However, two other conclusions can be reached with some certainty. Firstly, having a high share of coal fired generation will not necessarily deliver lower prices. Secondly, modern electricity systems do not need high levels of local dispatchable generation, let alone so-called baseload generation, to deliver highly competitive wholesale prices, while also operating with complete security over extended periods.

The data also show the value of interconnections over a wider area – in this case between South Australia and Victoria – in reducing the cost of supply when local variable generation is at low levels. Finally, the extreme price variability points to the potential importance of appropriately priced short/medium term storage in a system with high levels of variable generation.

Load shifting in time could also play a valuable role. While South Australia is providing an example to the rest of the country in how to transition to a zero emission electricity supply system, its residential off-peak storage electric water heaters provide an example of what not to do. Unlike New South Wales and Queensland, the two other states with a high proportion of off-peak electric water heaters, the network operator in South Australia cannot remotely control the timing of water heater switching, using ripple control, so as to optimise the benefits to the electricity system of these controllable loads. In South Australia, almost all systems are fitted with a pre-set time switch, and most of them switch on at 11 pm. On 28-29 November the water heaters came on when the spot wholesale price was around $65 per MWh. Had they been able to come on 12 hours earlier, the spot price would have been minus $35 per hour, to the potential benefit of both generators, which would have lost less money because the price would have risen somewhat, and consumers, because they were still receiving electricity at a zero of negative price.

This stupidity is the long-lived legacy of bad decisions made by the electric utility management for short term cost saving reasons over sixty years ago. With so many decisions with long term consequences to be made over the next few years, it is to be hoped that long-term thinking prevails at all times.

Appendix: Notes on methodology and data sources

Data on annual consumption of electricity, and seasonal peak demand, are for each of the six states. All other data are for the states constituting the National Electricity Market (NEM) only, i.e. they exclude Western Australia and the Northern Territory. All data are reported as annual moving averages. This approach removes the impact of seasonal changes on the reported data. Annualised data reported in *Australian Energy Emissions Monitor* will show a month-on-month increase if the most recent monthly quantity is greater than the quantity in the corresponding month one year previously. Most data are presented in the form of time series graphs, starting in June 2011, i.e. with the year ending June 2011. Some graphs start in June 2008. These starting dates have been chosen to highlight important trends, while enhancing presentational clarity.

Defining the meaning of the various terms used to describe the operation of the electricity supply system will help in understanding the data discussed.

Demand, as defined for the purpose of system operation, includes all the electricity required to be supplied through the grid level dispatch process, operated by AEMO. This includes all the electricity delivered through the transmission grid to distribution network businesses, for subsequent delivery to consumers. It also includes energy losses in the transmission system and auxiliary loads, which are the quantities of electricity consumed by the power stations themselves, mostly in electric motors which power such equipment as pumps, fans, compressors and fuel conveyors. Auxiliary loads are very large: in 2011 they amounted to 6.3% of total electricity generated and currently about 5.6%. Most of this load is at coal fired power stations, where it can be as high as 10% of electricity generated at an old brown coal power station and 7% at a black coal fired power station. Auxiliary loads are much lower at gas fired power stations, and close to zero at hydro, wind and solar power stations. Both demand and generation, as shown in the *Monitor* graphs, are adjusted by subtracting estimates of auxiliary loads. Thus demand, as shown, is equal to electricity supplied to distribution networks (and a handful of very large users that are connected directly to the transmission grid) plus transmission losses.

Generation is similarly defined to include only electricity supplied by large generators connected to the transmission grid. It does not include electricity generated by rooftop PV installed by electricity consumers, irrespective of whether that electricity is used on-site ("behind the meter") by the consumer or exported into the local distribution network. From the perspective of the supply system as a whole, the effect of this generation, usually termed either "embedded" or "distributed" generation, is to reduce the demand for grid supplied electricity below the level it would reach without such distributed generation. That effect can be clearly seen in the regular total generation graph; the gap between the red line – electricity sent out to the grid from large grid connected power stations – and the yellow line – that electricity plus estimated electricity generated by distributed solar systems – is the electricity supplied by those systems.

All electricity data are sourced from AEMO, which the *Australian Energy Emissions Monitor* accesses through NEM Review. The main source of petroleum data is *Australian Petroleum Statistics* and the main source of gas data is the Australian Energy Regulator's weekly *Gas Market Report*.