Australian National University

Australian National University Institute for Climate, Energy & Disaster Solutions

Australian Energy Emissions Monitor

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Australian Energy Emissions Monitor

Contents

Key Points

- As wind and solar generation continue to supply a growing share of electricity in eastern Australia, i.e. the National Electricity Market (NEM), electricity generation remains the only significant source of emissions reduction.
- Total consumption of gas continues at an almost unchanged level, while, except for domestic aviation, consumption of petroleum products has returned to pre-pandemic levels.
- Month by month examination of consumption of energy supplied by both electricity and gas shows a consistent and very clear seasonal pattern.
- Seasonal demand variation presents a particular challenge for electricity generation which, in mainland eastern Australia, is currently met by varying output from coal fired generators. This challenge will be made much larger, particularly in Victoria, if and when consumers switch away from gas and towards electricity.
- As the supply system shifts towards more wind and solar generation, new approaches will be required to limit costs to consumers arising from the need to deal with seasonality in demand.
- The Australian Energy Market Operator (AEMO)'s *Integrated System Plan* (ISP) states that "overbuild" of wind and solar generation, accompanied by output curtailment during protracted periods of lower consumption, will be the least cost option for addressing this.
- Such an approach will require new policy instruments to support investments in generation that will only be required for part of each year.

Introduction to the October 2022 issue

Welcome to the October 2022 issue of the *Australian Energy Emissions Monitor*, which is a bi-monthly publication of the ANU Institute for Climate, Energy and Disaster Solutions (ICEDS), providing timely analysis of the most recent trends in energy related greenhouse gas emissions. The publication is intended as a service to Australia's energy community.

This issue consists of two sections. The first is an update, on a monthly basis, of total emissions arising from consumption of electricity, gas, and petroleum products in the five states of eastern Australia – electricity to the end of September, gas to the end of August, and petroleum products to the end of July. For the first time, these data are plotted on both a moving annual total basis and also on a month by month average basis. The moving annual graphs show, of course, that emissions from electricity generation are gradually decreasing, while energy consumption has been staying almost constant. However, the monthly data show a very marked seasonality in consumption of both electricity and, in particular, gas. In energy terms, very much more gas is consumed during the winter months than at other times of the year. More electrical energy is also consumed during winter than at other times of the year, but there is also a secondary energy consumption peak during the summer months.

The second section looks more closely at month by month consumption of energy in Victoria and New South Wales (NSW). This leads into an examination of the possible effect on monthly consumption of electrical energy if residential energy use shifts from gas to electricity, i.e. if residential energy use is electrified, as has been widely advocated. If this shift becomes widespread, much more electrical energy will be required during the period from, as a generalisation, mid-May to mid-September, than in any other individual months. Such a pattern of annual electricity consumption will present a significant challenge to the operation of an electricity supply system dominated by wind and solar generation. In mainland Australia such monthly energy consumption variation would be far too large to be addressed economically by any form of storage. While potentially some years into the future, this is a major problem that has to date received almost no attention in the extensive discussions about the future of the National Electricity Market, apart from a brief and indirect mention on one page of the 2022 *Integrated System Plan*.

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

Update on energy combustion emissions in eastern Australia

Figure 1 updates the trend in emissions in eastern Australia, i.e. Australia excluding WA and the NT, arising from energy consumption to the end of September 2022 in the case of electricity generation, to the end of August for gas and the end of July for petroleum product emissions. The steadily declining trend in emissions for coal and gas used to generate electricity continues, while, on a moving annual basis, emissions from all other uses of gas and petroleum products remain almost unchanged.

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

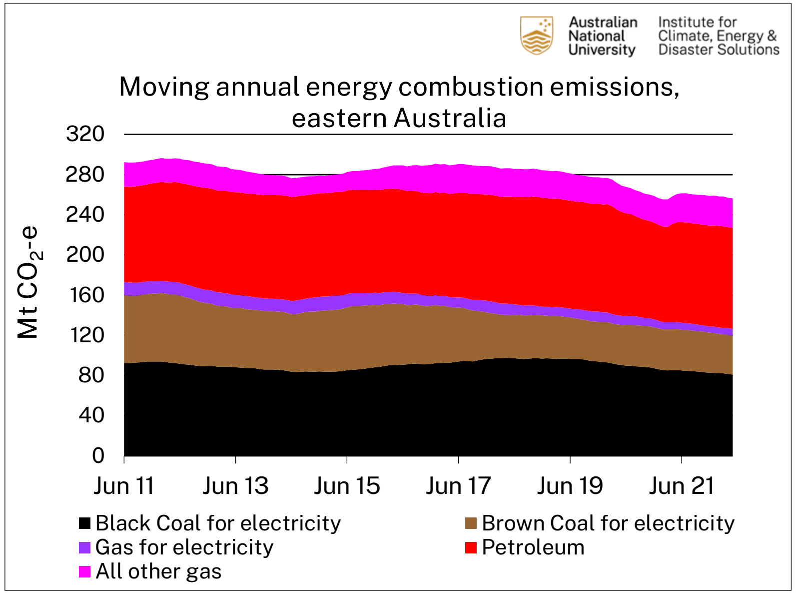


Figure 2, which is a new graph, shows the final energy in the quantities of each of the three main final energy types delivered to consumers. Two features are important in comparing the two graphs.

Firstly, with electricity generation still dominated by coal fired generation, electricity is much more emissions intensive (emissions per unit of energy supplied) than either gas or petroleum products. However, in terms of final consumption this is largely offset by the much greater efficiency with which electrical energy can be converted to useful energy services than either of the other two fuels. For example, for space heating, electric heat pumps (reverse cycle air conditioners) deliver four to five times more heat per unit of input energy than a gas heater. A similar sort of advantage applies to use of electric motors, compared with internal combustion engines, for transport. This conversion efficiency advantage largely, if not completely, offsets the higher emissions intensity of delivered electricity, and this advantage will increase as the electricity supply system decarbonises.

Secondly, annual consumption of all three fuel types has been roughly constant, at the scale used in Figure 2, while the decrease in electricity generation emissions is clearly visible. There has been no significant change in emissions from consumption of either petroleum products or gas, because there has been no significant change in either the fossil carbon content of these fuels or the volumes consumed. The stark difference between trends in electricity generation, and trends in emissions from consumption of petroleum fuels and gas, is more clearly seen in Figure 3. Since 2015-16, electricity generation emissions in the NEM have contributed all the emissions reductions from energy consumption in eastern Australia.

Figure 2: Moving annual energy consumption, eastern Australia, 2011-21

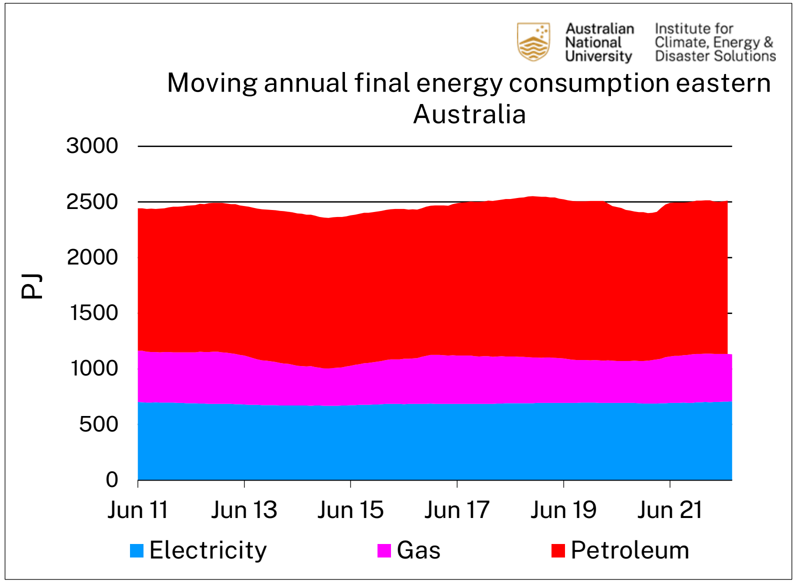
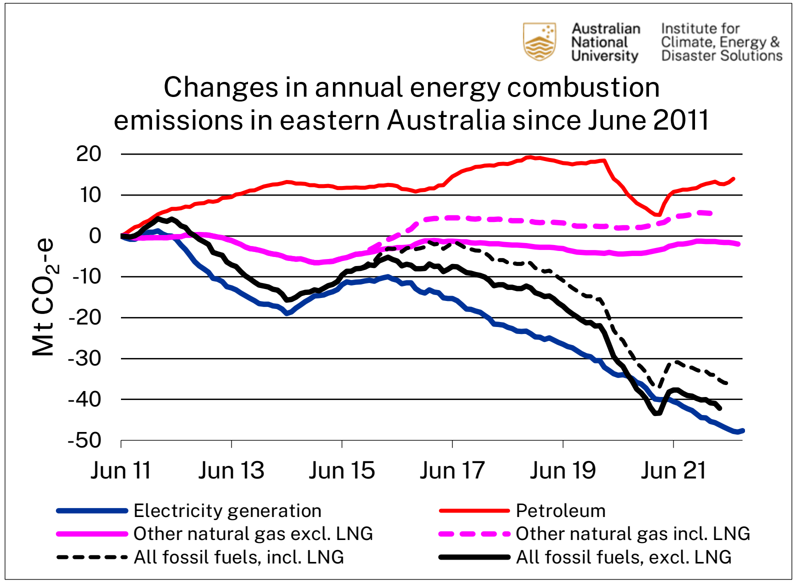


Figure 3: Moving annual energy consumption, eastern Australia, 2011-21



A different way of understanding the energy consumption and emissions data is shown in Figures 4 and 5. Both emissions and energy consumption are plotted on a monthly basis, as the average daily values for each month.

Figure 4: Monthly average energy combustion emissions, eastern Australia

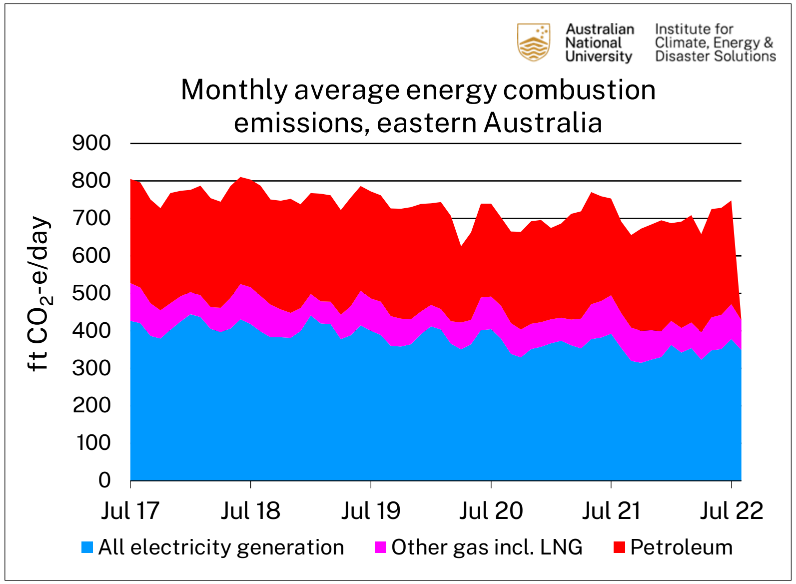
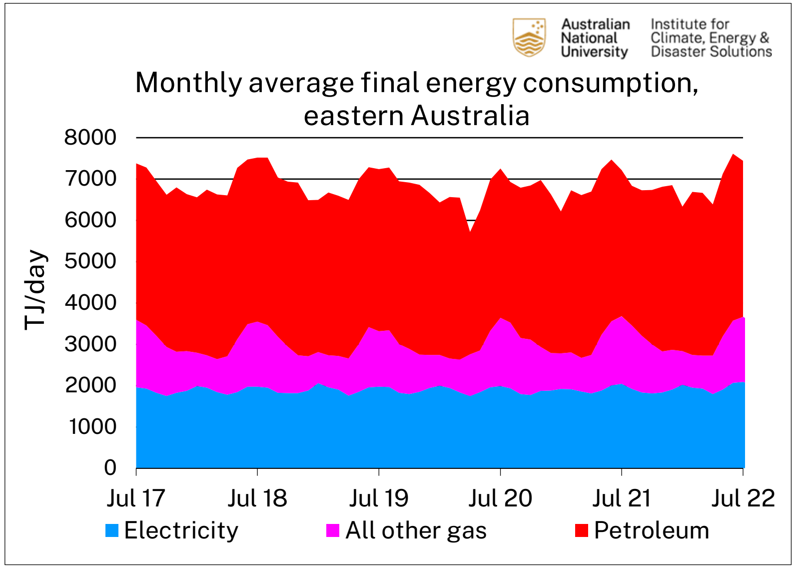


Figure 5: Monthly average final energy consumption in eastern Australia



The key feature of these graphs, not visible in the data when plotted on a moving annual basis, is that monthly consumption of gas in particular shows a strong seasonal pattern, being much higher during the winter months than at any other time of the year. There is a similar, though much smaller, seasonal pattern in electricity consumption. Seasonality has very important implications for the future of the electricity grid, as supply shifts towards renewable generation and away from coal, and as residential consumers, in particular, switch away from gas and towards all-electric consumption. These implications have so far received very little public attention in the debates around the future of the NEM. They are examined in more detail later in this *Monitor* issue.

The August issue of the *Monitor* included a discussion of how the emissions trends shown in Figure 3 relate to the formal 2030 emissions reduction target of 43% below 2005 emissions level. At that time, AEMO's final 2022 *Integrated Systems Plan* (ISP), released at the end of June, suggested that likely reductions in NEM generation emissions could continue to contribute much, but not all of the required emissions reduction. This assessment was based on the informed judgment of extensive consultation with large numbers of electricity industry participants, undertaken by AEMO as key input to the ISP, and was clearly reliant on the formal commitments and plans of the state governments of NSW, Victoria and SA.

At that time, Queensland, which is currently responsible for 33% of NEM generation emissions, had a longstanding verbal commitment to major growth in renewable generation, but no plan as to how that might be achieved, and few firm achievements. In September, however, Queensland joined the other states with the release of what is called its *Energy and Jobs Plan*. Despite the use of the word Energy in the title, the plan is in fact about electricity, not all energy, with its centrepiece a commitment to achieve 50% of renewable generation by 2030. One component is a commitment to build extensive electric vehicle charging infrastructure. However, as with other states and the Commonwealth there are no other major proposals to achieve faster reductions in transport energy emissions, nor from the very large emissions from use of diesel fuel in mining, or emissions from coal and gas used in mineral processing and other industrial activity.

Implications of the seasonality of energy consumption

Figures 6 and 7 show monthly average daily consumption of electricity and gas, in, respectively, NSW and Victoria over the past six years. Electricity consumption includes electricity supplied from rooftop solar PV. Use of monthly averages of daily consumption removes the effect of different numbers of days per month on monthly consumption and also largely removes the effect of weekends and public holidays which would dominate daily data. It therefore makes seasonal changes much easier to see. Key features are:

- NSW uses considerably more electricity than Victoria, whereas Victoria uses almost twice as much gas as NSW;
- consumption in Victoria shows much more seasonal variation;
- consumption of electricity is seasonal in both states, with more being consumed in winter and in summer than in other months;
- consumption of gas is also seasonal, but with a single annual peak in winter;
- seasonality of gas consumption is extreme in Victoria, with maximum daily consumption, from June to August, up to almost three times higher than in January and February.

In Queensland and South Australia, the seasonality of electricity consumption is similar to NSW and Victoria, whereas in Tasmania there is only a winter peak.

Figure 6: Average daily by month consumption of electricity and gas: NSW

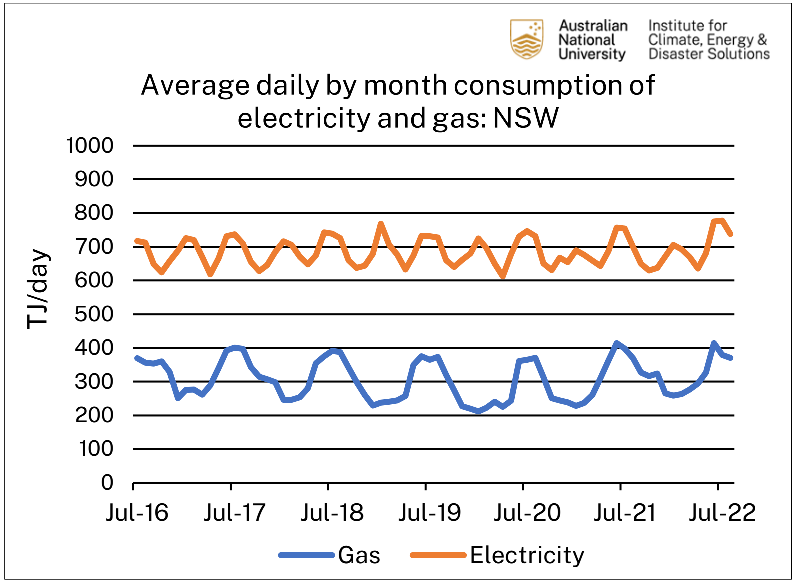
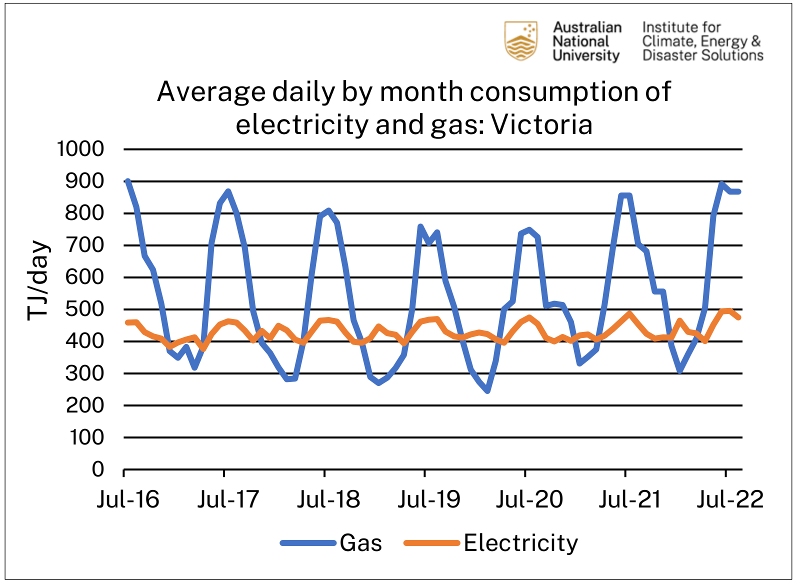


Figure 7: Average daily by month consumption of electricity and gas: Victoria

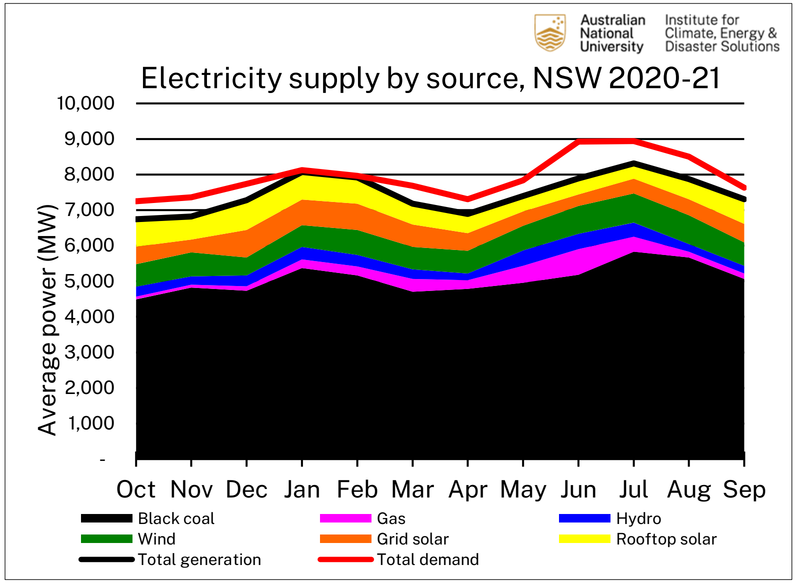


Seasonality of consumption is of course caused by the use of energy for space conditioning in buildings – heating using either electricity or gas and cooling using electricity. In addition, there is a modest increase in energy used for water heating in winter, particularly in southern Australia, because water input to heaters is slightly colder in winter. Of course gas can provide only winter heating, whereas electricity can be used to provide both heating in winter and cooling in summer. Thus consumption of gas shows only a single annual seasonal peak, whereas electricity consumption shows two peaks, in both winter and summer. The seasonality of gas consumption is more extreme in Victoria for two reasons; firstly, because a much higher proportion of dwellings use gas for heating than in any other state and, secondly, because a much higher proportion of the population lives in regions with colder climates (National Construction Code Climate Zones 6 and 7) than in any other state except Tasmania (and the ACT).

For gas supply, supplying with seasonal variation is relatively straightforward, because supply is directly linked back to the extraction of primary fuel from underground conventional and coal seam wells. In addition, the gas supply system is able to accommodate shorter term peaks in demand lasting a few days by what is called linepack, meaning temporarily increasing the pressure of gas in the very long transmission pipelines linking gasfields to markets.

For electricity supply, seasonality is more of a challenge. Figures 8 to 13 show monthly average supply and demand, expressed in MW, throughout 2020-21 for each of the five regions (states) making up the NEM, and for the NEM as a whole. In each state graph, the gap between demand (the red line) and supply (the black line) represents net interconnector flows between states.

Figure 8: Monthly average electricity supply by source 2020-21, NSW



Demand in all five states shows seasonality, with more electrical energy used in the summer months and the winter months than in the spring and autumn seasons, though the difference is very small in Queensland. Queensland is also the only state in which more energy is consumed in summer than in winter, reflecting the sub-tropical/tropical climate of the state.

Looking first at the "coal states", there is, of course, more solar generation in summer than in winter. In Victoria, the extra electricity supply available is exported to both NSW and South Australia, which enables the coal generators in Victoria to operate at a near constant level all year round, while supplying more of the demand within the state during the winter months. The converse applies in Queensland, where there is more surplus generation capacity available to be exported to NSW in winter than in summer. For coal fired generators in NSW, the effect is to out-compete their higher cost supply all year round and also to make demand much higher in winter than in summer. These outcomes of NEM market dynamics are one factor contributing to the earlier than expected closure of Liddell power station during the coming months, and Eraring a few years later.

In South Australia, the marginal source of supply is gas generation, which is more costly than coal generation. Consequently, the state imports marginal supply from Victoria, except during the peak of winter, when it consequently has to use more gas. During 2022 there was also more wind generation within the state than at other times of the year, but the difference is not great and also varies from year to year.

In Tasmania, seasonality of electricity demand is less than might be expected, given both the climate and the fact that only a minority of buildings use gas heating. The reason is that large industrial consumers, which typically use electricity at a constant rate all year round, account for a much larger share of total electricity demand than in other states.

Most of the Tasmanian hydro generation system consists of power stations which are either run-of-the-river (meaning that they are backed by very little storage capacity) or backed by relatively small storage. Combined with Tasmania's winter dominant rainfall pattern, this means that these power stations are able, and, indeed, must, given their relative lack of storage, supply the majority of demand during winter and early spring. The exceptions are the two largest power stations, Poatina and Gordon, supplied respectively from Great Lake and the Gordon Dam. These schemes are able to store winter run-off and use it later in the year and through summer, as Figure 12 shows happened in 2021-22. In addition, Tasmania augmented supply from within the state during summer by importing coal-fired generation from Victoria.

Figure 9: Monthly average electricity supply by source 2020-21, Victoria

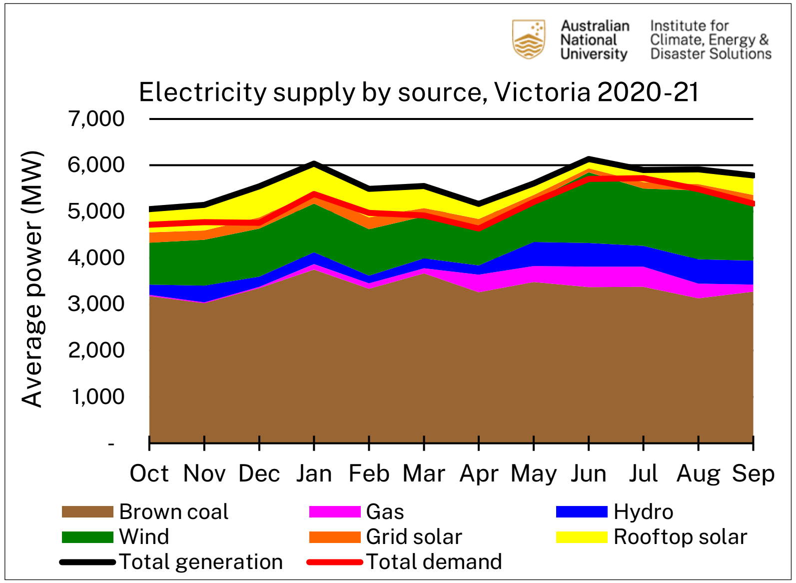


Figure 10: Monthly average electricity supply by source 2020-21, Queensland

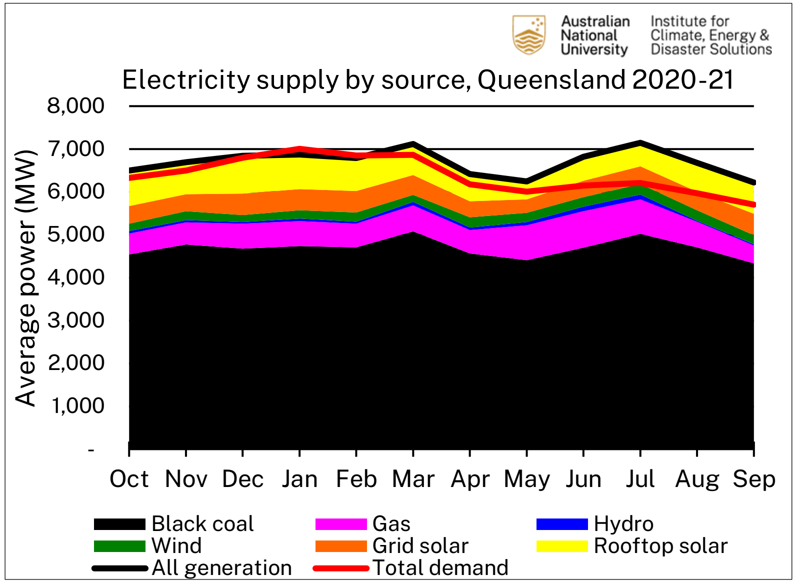


Figure 11: Monthly average electricity supply by source 2020-21, South Australia

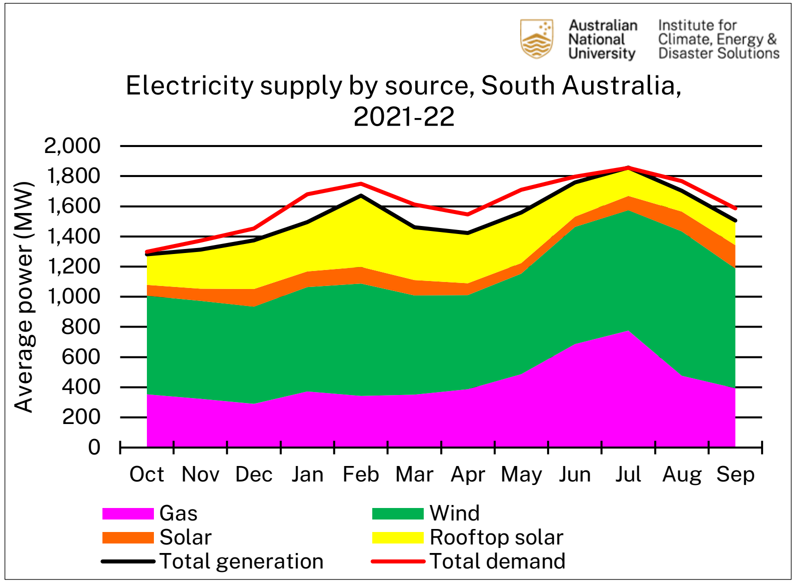


Figure 12: Monthly average electricity supply by source 2020-21, Tasmania

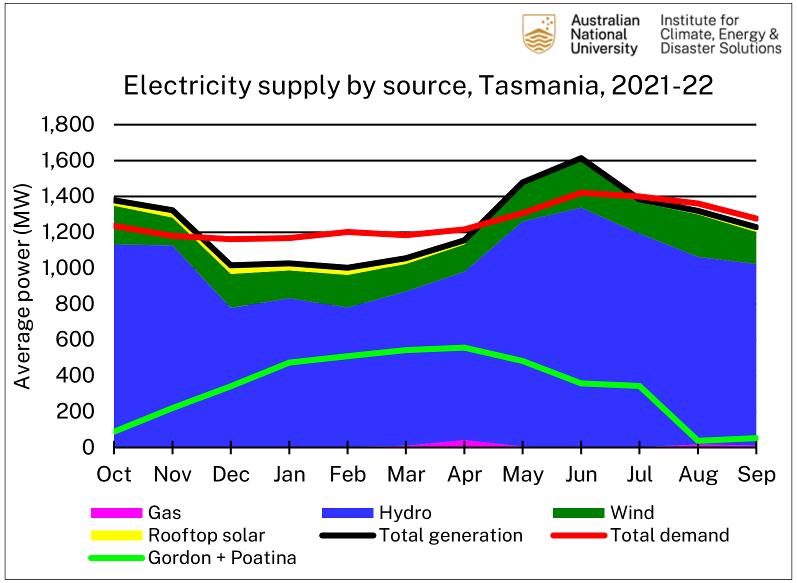
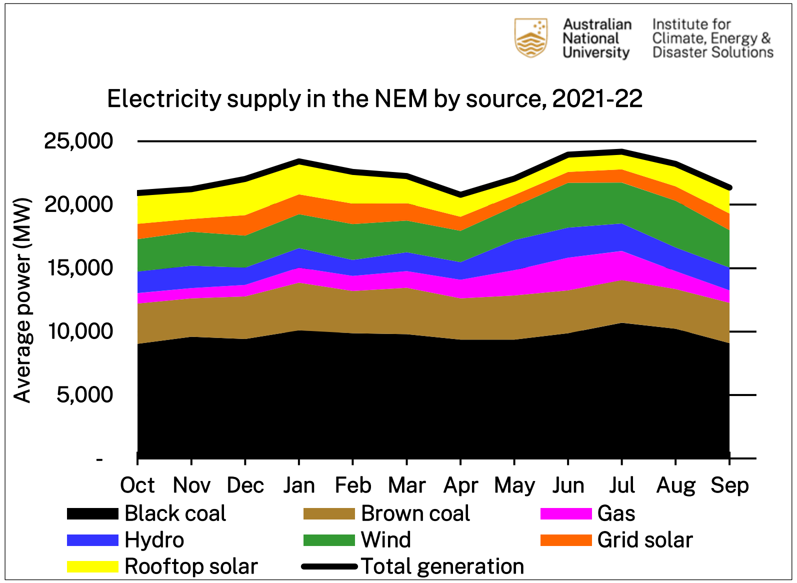


Figure 13: Monthly average electricity supply by source 2020-21, total NEM

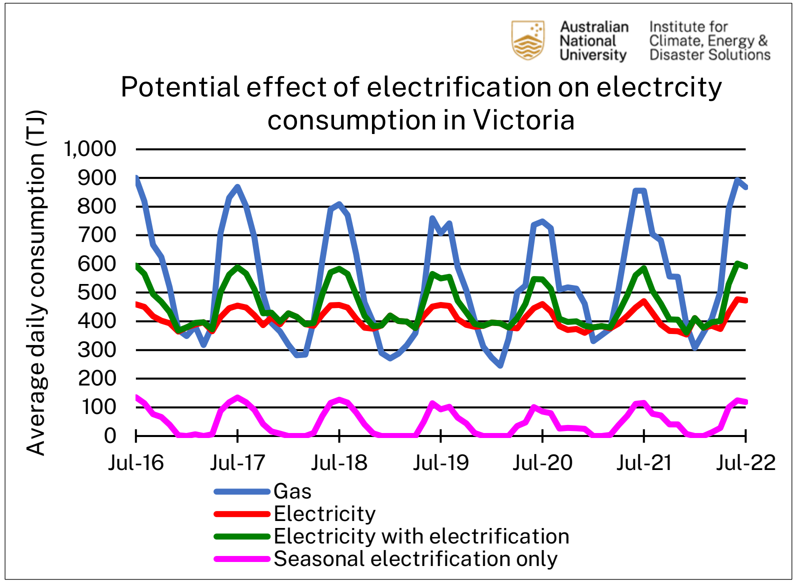


These facts are important background to understanding the recent announcement by Minister Bowen that the Commonwealth would contribute to the cost of building Marinus Link, the proposed second sub-sea cable transmission link between Victoria and Tasmania. This project will do nothing to make additional generation capacity available to supply higher seasonal consumption of electrical energy on the mainland. If more wind generation is built in Tasmania, there will be more periods of a few days when the Tasmanian system as a whole has additional space capacity to export to the mainland. Furthermore, the so-called Battery of the Nation, proposed by Hydro Tasmania and the Tasmanian government, is simply another pumped hydro scheme, in principle not dissimilar to Snowy 2.0, in that it will use at least one existing storage. Neither scheme will do anything to support higher seasonal consumption of electricity in winter.

Hence, in the longer term, seasonality of electricity demand, particularly winter demand, will present a significant challenge to electricity supply as the share of supply from renewable generators steadily grows. In Victoria, and also South Australia, wind generation is on average somewhat higher during the winter months than at other times of the year. However, this effect is not large and neither is it particularly reliable. Moreover, the challenge will become even larger as residential consumers switch away from gas towards electricity. The impact of such a change can be seen, in broad-brush terms, by a simple calculation for Victoria, where, as can be deduced from Figure 7, the impact will be particularly large. Assume that all of the difference between summer and winter demand, as shown in Figure 7, is attributable to space and water heating. Assume that gas heaters are replaced by reverse cycle air conditioners and heat pump water heaters. Further assume that these electric appliances deliver four times as much useful heat per unit of energy consumed, compared with the output of useful heat per unit of gas consumed by gas appliances.

The resultant hypothetical increase in electricity consumption in Victoria during the winter period is shown in Figure 14. As can be seen, the annual total varies from year to year, but the average is roughly 4,000 GWh per year, equal to nearly 10% of Victoria's total annual consumption of electricity. While this demand for additional electricity could certainly be reduced, over time, by upgrading the thermal efficiency of residential and commercial buildings, it will not be eliminated.

Figure 14: Potential effect of electrification on electricity consumption in Victoria



This additional consumption cannot be supplied by large storage schemes, i.e. pumped hydro, as they operate by cycling energy, available from temporary surplus electricity supply, over periods of usually not more than a few days. Additional seasonal demand can be supplied only once per year, as, by definition, there is little or no surplus energy available during the period when the additional demand occurs. This is achieved in Tasmania, where there is no second (summer) peak in annual electricity consumption, where total consumption is relatively small, and where the major dams in the Hydro Tasmania system have sufficient capacity when full to supply more than the total annual electricity consumption in the state.

Mainland hydro capacity is many times smaller, relative to demand, than Tasmanian hydro. In addition, storage is smaller relative to annual supply of hydroelectricity and the timing of releases from storage is further constrained by the need to store water to meet seasonal demands for irrigation water. Specifically, the storage capacity of Snowy Hydro 2.0 is only 350 GWh and is, in any case, not additional or surplus energy. It is therefore completely irrelevant to meeting seasonal demand; its intended purpose is to store energy for a few days to cover periods of low wind speed and/or protracted cloudiness.

AEMO does not explicitly address this seasonality issue in its 2022 ISP. However, on p. 46, under the heading "Curtailment of VRE [Variable Renewable Energy] will sometimes be efficient", it argues:

> "*Curtailment or spill of VRE generation is forecast to occur when there is higher solar generation: during daylight hours and during spring and summer. Accepting this constraint while building enough VRE to meet the energy needs of winter is likely to be more efficient, on estimated technology costs, than building less VRE but more seasonal storage.*"

Given that the requirement for additional electrical energy will occur in southern Australia, in winter, wind generation is likely to be a lower cost option than solar generation, unless the relevant capital cost of solar farms is significantly lower than the cost of windfarms. The capacity of VRE generators affected by this approach would be quite considerable. Between May and September this year, the nearly 3.8 GW of wind farm capacity in Victoria generated approximately 4.6 TWh, i.e. not much more than the additional winter demand which could arise from electrification, as calculated above. AEMO goes on to state that:

> *"Market reforms are being developed by the Energy Security Board (ESB)39, with the aim of ensuring that incentives are in place for investors to develop an optimal level of VRE capacity."*

It is not clear, however, in the documents publicly released by the ESB in August, how or where consideration is given to the particular issue of seasonal demand.

Operating a significant proportion of mainland wind generation at a capacity factor substantially less than its potential maximum value will of course increase the wholesale cost of electricity throughout the year, all else being equal, and most of this cost burden will fall on residential consumers. Over the last few years, several state and territory governments have instituted programs which subsidise the cost of installing residential rooftop solar and/or batteries, as a means of both accelerating the electricity system transition and helping households over the longer term to offset the higher costs of network supplied electricity.

For obvious reasons, rooftop solar will not do much to assist households with high electric heating costs in winter, particularly in Victoria, where the cost burden will be most severe. A better use for subsidies, and one which would also help to reduce the cost of air conditioning in summer, would be to reduce the demand for electrical energy for winter heating by helping to upgrade the notoriously poor average thermal efficiency of houses.

Appendix: Notes on methodology and data sources

Data on electricity generation and electricity consumption is for the five states constituting the National Electricity Market (NEM) only, i.e. data exclude Western Australia and the Northern Territory. All data are monthly totals, sourced from AEMO, accessed through NEM-Review. Data on gas consumption are also for the five eastern states only; sourced from the Australian Energy Regulator's weekly *Gas Market Report*. The main source of petroleum consumption data is monthly sales of petroleum products, compiled by the Department of Industry, Science, Energy and Resources and published as *Australian Petroleum Statistics*. Unlike the sources used for electricity and gas data, petroleum data covers the whole of Australia at the state level. The emission factors used for petroleum products and gas are based on *National Greenhouse Accounts Factors* and, in the case of petroleum products, are CO_2-emission factors only, because the (much smaller) emission factors for methane and nitrous oxide depend on the type of equipment in which the petroleum products are used.

Many of the graphs in *Australian Energy Emissions Monitor* are presented as moving annual totals. 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. 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. Large users include the three pumped hydro schemes in the NEM, but since these both consume and generate electricity, net consumption, averaged over time, is only the difference between consumption and generation.

Generation is defined to include only electricity supplied by large generators connected to the transmission grid. The numbers reported by AEMO are "as generated" generation, meaning the generation required to supply total demand, including auxiliary loads. However, most of the analysis and results presented in the *Monitor* show sent out generation, meaning as generated generation, minus auxiliary loads. To estimate auxiliary loads, the *Monitor* uses auxiliary load factors for each power station, published by AEMO and used in all its modelling work, including the modelling supporting the Integrated System Plan. Similarly, the *Monitor* uses AEMO figures for the emissions intensity (emissions per unit generated) of each power station.

Demand 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. This has been growing very rapidly and in the year to December 2021 totalled over 16 TWh. Also excluded is generation from landfill and sewage gas plants, and various other small generators, totalling about 2 TWh. All these types of small generators supply into their local distribution network, not the NEM grid. 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.