Abstract
The opportunity to achieve a wind and solar energy only Australian national electricity market (NEM) grid is linked to the development of massive energy storage systems. Photovoltaic solar energy is unavailable nighttime and reduced when it is cloudy or raining. Wind energy also drops some days to zero, with similarly large fluctuations between maximum and minimum energy supplies. This fundamental aspect is being ignored when only trying to increase the nominal capacity of wind energy and solar photovoltaic facilities. The need for a massive energy storage system to properly use this increased capacity is highlighted by the high-frequency energy generation data by source that we show for the NEM that is covering most of South Australia, Victoria, Tasmania, New South Wales, and Queensland, with the only exception of Western Australia and the Northern Territory. This analysis highlights the present energy storage needs for a NEM wind and solar only. The nominal capacity of wind and solar, and the energy storage, that is supposed to increase up to unbelievably high values, to only cover the electricity production, is due to increase even more, to cover the TPES demand, and not only the electricity demand, of a country without combustion fuels.

KEYWORDS
Australia, energy storage, solar energy, wind energy

1 | THE AUSTRALIAN NATIONAL ELECTRICITY MARKET GRID

The energy markets and systems in southeast Australia are run by the Australian Energy Market Operator (AEMO). The Australian national electricity market (NEM) grid, covering South Australia (SA), Tasmania, Victoria (VIC), Australian Capital Territory (ACT), New South Wales (NSW), and Queensland (QLD), is presently fed with a small amount of renewable energy only, it strongly depends on the combustion of fossil fuels to cover the demand. The NEM is one of the world’s longest grids, stretching for about 5000 km from Port Douglas, Queensland to Port Lincoln, South Australia. The NEM grid also serves Tasmania across the Bass Strait. Because of their distance, Western Australia (WA) and the Northern Territory (NT) are not connected to the NEM.

Presently, the peak power capability of the NEM is 46 848 MW, while the total registered (nominal) capacity of wind energy in the NEM is 6702 MW. The nominal capacity of wind energy is not the power of the wind energy generation, that occurs at a fraction of the nominal capacity, largely variable over the year. Same of solar energy, that additionally is only available during daylight times. As wind and solar energy
are fluctuating, even if the nominal renewable energy power supply matches the peak power demand of the grid, this is not enough, as this renewable energy is generated at a variable fraction of the nominal power. On an annual average, this fraction for wind is about 30-35%. Hence, the nominal capacity of 6702 MW drops to an average annual generating capacity of 2234 MW in actual terms. Not only the annual average capacity factor, the ratio of actual generating power to nominal capacity, is an issue. The grid must be balanced at any time. Thus, at any time, wind and solar energy inputs must balance the grid demand. As it will be shown later, the wind energy input to the grid may drop instantaneously to values below 5% or rise to values about 60%. Regarding solar, during the night, production is always zero, and fluctuations are also large during daylight times. Right now, apart from a small contribution by hydroelectric energy, it is the role of combustion fuels to produce a balanced grid, dealing with solar, and wind energy inputs moving unpredictably from minimums to maximums.

Australia has many areas scarcely populated without too much water (population density of less than 1 person per square km excluding the large capital cities, center of Australia mostly arid), and without too many mountains, with a grid that is everything but equally covering the available land, being the surface covered by a grid much less than the area uncovered. As shown in Reference 3, and Figure 1, most of the Australian land, including generous portions of South Australia, New South Wales, and Queensland, are off-grid, and, the most of Western Australia and the Northern Territory, are off-grid. The NEM grid is the part of the grid covering the south-east states.

Pumped hydroelectric energy storage (PHES) is the easiest way to supply electric energy storage. PHES is characterized by round-trip efficiencies of 70% to 80%, much less than the round-trip efficiency of li-ion batteries, rated 95%. Hydro gravity facilities already supply power-on-demand for 6% of the total power supply to the NEM. These Hydro gravity facilities are mostly found in Tasmania and the boundary region between New South Wales and Victoria. One of these hydro gravity facilities, the 1800 MW (according to Snowyhydro, or AEMO, or OpenNEM, or AWS) Tumut 3, has already PHES capabilities, having three turbines and three hydraulic machines working as pump or turbines according to the needs. Despite Tumut 3 is reported by Wikipedia as a 1800 MW PHES facility, it is actually 1500 MW hydro-gravity facility with 600 MW pumping power. Another PHES is the 500 MW Wivenhoe Power station. The Tumut 3 Power Station, completed in 1972, was the first PHES of Australia. There are two other smaller PHES facilities to mention, Shoalhaven, and Jindabyne. The easiest way to increase the energy storage of the Australian NEM grid is to retrofit/upgrade the hydro gravity facilities with pumping.

**FIGURE 1** National electricity transmission lines in 2014. Image reproduced modified from upload.wikimedia.org/wikipedia/commons/d/d4/NationalElectricityTransmissionLinesMapAustralia.jpg. Original image produced by Geoscience Australia. An image distributed under creative commons CC BY 4.0
capabilities and addition of a lower reservoir. Added PHES facilities will have to be located along the coast close to the grid, as unexploited good sites for PHES in the interior are in short supply. According to, the Top Two largest hydro plants in Australia by capacity are the 1500 MW Tumut 3 and the 1500 MW total Murray 1 and 2, both part of the Snowy Mountain Hydro Scheme. Murray and the 616 MW capacity Upper Tumut, also part of the Snowy Mountain Hydro scheme, are the Top Two largest hydro plants in Australia by capacity by generation 2008-2012, at 8103.678 and 4235.144 GWh.

2 | NEM WIND INPUTS

The NEM registered capacity for wind is 1503 MW in New South Wales, 632 MW in Queensland, 2142 MW in South Australia, 308 MW in Tasmania, and 2116 MW in Victoria, for a total of 6702 MW. As the NEM grid annual average capacity factor is about 33%, with “lows” down to below 5%, and “highs” up to above 65%, this means that wind power is delivered to the grid at an average annual power of 2200 MW, but “lows” of 330 MW or “highs” of 4300 MW everything but infrequent.

Figure 2 (from Reference 2) shows the sum of all the wind energy inputs to the NEM grid in Australia, that as previously written, cover a significant part of the states of South Australia, Tasmania, Victoria, New South Wales, and Queensland, plus the Australian Capital Territory, that is, an exceptionally large land area, during May 2019. (Figure 2A) Shows the location of wind energy facilities. Australia is about 4000 km wide between its eastern and western extremities, while it is about 3860 km long between its northern and southern extremities, for a total surface of 7.692 million km². The facilities are mostly found along the coast from Port Lincoln, in South Australia, to Port Douglas, in the tropical north Queensland, that is about 5000 km apart. The results for wind energy are then shown, like power (Figure 2B) and percentage of nominal power, that is, the capacity factor, (Figure 2C).

As previously mentioned, the wind farms of Australia work on an annual average with capacity factor (actual generating power to nominal power) of 30%-35%, that is about same of other countries, for example, the United States. What is relevant, are the fluctuations about this average, not only the minimums, but also the maximums, as the grid must always be balanced in between demand and supply, and no energy input should be wasted or missing. (Figure 2D,E) present the capacity factor for wind energy in 2 days of low production, May 6 and 22. Similar lows are found in other 7 days in this month.

In a high-frequency statistic of 5 minutes (but a much higher frequency of 1 minute or less would be more appropriate), cases of low below 5% capacity factor, or high above 60% capacity factor, are thus not uncommon for wind, despite the wind energy facilities are distributed over a huge area. Apart from the variations that are clear with a

![Figure 2](image-url)
high-frequency statistic, also relevant are the seasonal and interannual variations.\textsuperscript{15}

With a 5 minutes resolution, the average wind energy contribution over this huge area may go up to above 60\% of nominal capacity, but also down to 5\% of nominal power. From the 27th to the 29th, wind energy is produced in four occurrences at a rate of above 60\% of the nominal capacity. From the 15th to the 23rd of the month, wind energy is produced in four occurrences also at a rate below 5\% of the nominal capacity. About the sixth of the month, there is one more occurrence of wind energy produced at a rate below 5\% of the nominal capacity. With a minute resolution, that is more proper to describe a grid status, the situation is highly likely worse. May is not the worse month in a year for wind energy generation in Australia. Energy production of other months can be found in\textsuperscript{2} or\textsuperscript{12}

Without combustion fuels, are the minimum values of the wind energy capacity factors, and not the annual average, that must cover the demand, as solar photovoltaic is only available during the daylight time when it is not raining. Additionally, also the maximum values create issues, as a grid without energy storage cannot accept extra energy. Thus, wind energy needs significant energy storage facilities to avoid wasting any renewable energy input and to always have enough renewable energy to cover the needs.

3 | NEM SOLAR INPUTS

The NEM registered capacity for solar (excluding rooftop) is 850 MW in New South Wales, 1579 MW in Queensland, 378 MW in South Australia, zero in Tasmania and 430 MW in Victoria, for a total of 3237 MW. Every day, “lows” are zero, while “highs” may approach 100\% depending on the season and the daily weather. This means that solar power from facilities is delivered to the grid with “lows” of zero and potentially up to 3237 MW of power. Added to solar farms, solar power is also delivered by solar rooftop installations of even larger registered capacity but more difficult accounting.

Figure 2 has proposed the wind contribution, that is, what would be available every night (apart from hydroelectric) without energy storage. During daylight times, there is also solar energy input. Figure 3 shows the sum of all the solar energy inputs to the NEM grid in Australia, during May 2019. (Figure 3A) presents the location of the solar energy facilities, almost entirely solar photovoltaic (the Gullen Range Solar Farm that is Solar Thermal has a registered capacity of only 10 MW) and (Figure 3B) the power. Solar energy is unavailable nighttime, and the total solar power fluctuates during the daylight time between minimums of less than 900 MW and maximums of more than 1600 MW during this month. (Figure 3C) presents a similar contribution from rooftop solar. This contribution similarly fluctuates, between minimums of less than 2400 MW and maximums of more than 3800 MW during this month, obviously during daylight. The frequency of the solar rooftop contribution is 30 minutes instead of the 5 minutes of the other sources. Energy production of other months can be found in Reference 2. Also, for the sun, apart from the variations shown that are clear with a high-frequency statistic, also relevant are the seasonal and interannual variations.\textsuperscript{16}

Without combustion fuels, the daylight-time-only solar energy supply creates issues, that are further worsened by
the fluctuations between maximums and minimums from 1 day to the other, as the total inputs to a grid without energy storage must balance the demand.

4 | NEM HYDROELECTRIC INPUTS

In addition to solar photovoltaic and wind, despite being mostly arid, without too many mountains and rivers, Australia also has an extremely important production of hydroelectric energy. In 2013, hydroelectric energy was 8% of the total electricity. The hydroelectric share of Australia’s total electricity is projected to fall around 3.5% in 2030. The NEM registered capacity for hydro is 2525 MW in New South Wales, 644 MW in Queensland, zero in South Australia, 2270 MW in Tasmania and 2238 MW in Victoria, for a total of 7677 MW. Australia has the best sites of hydro gravity already developed. Hence, while hydroelectric energy may help to balance a grid where the combustion fuels supply is reducing, it may fail to address the balancing issues of a grid without combustion fuels supply.

Figure 4 shows the sum of all the hydroelectric energy inputs to the NEM grid in Australia, during May 2019. (Figure 4A)
presents the location of the hydroelectric facilities and (Figure 4B) the power. Most of the facilities are Hydro–Gravity, with a small contribution from Run of River. The 500 MW Wivenhoe Power Station, that is Pump Storage, is included in this graph. The Snowy Hydro 1500 MW Tumut 3, here considered as Hydro - Gravity, also has PHES capabilities, with pumping for 600 MW. The figure also shows in (Figure 4C) the power of the 1650 MW Tumut 3 partially PHES Power Station, in (Figure 4D) the power of the 500 MW PHES Wivenhoe Power Station, and in (Figure 4E) the power of the 1500 MW Murray Power Station. Tumut 3 and Murray are both parts of the Snowy Mountains scheme. Despite smaller capacity, and not having pumping, Murray is producing more electricity than Tumut 3, also working more often and for longer periods.

5 | NEM OUTPUTS

Figure 5 presents the total power contributed to the grid by the different sources, that in addition to wind, solar, rooftop solar, and hydro, then includes combustion fuels, coal seam methane, diesel, kerosene, waste coal mine gas, bagasse, black coal, brown coal, natural gas, natural gas/diesel, natural gas/fuel oil, that are all contributing directly to the carbon dioxide emission, during May 2019. Total energy production of other months can be found in Reference 2. Without combustion fuels, the intermittent wind contribution, Figure 2, plus the intermittent solar contribution, Figure 3, and the only dispatchable small amount of hydroelectric energy discussed above, Figure 4, cannot balance the grid without energy storage.

6 | PHES BASICS

The easiest way to understand the power of generating energy in a PHES facility is to look at the equation for hydropower:

\[ P = \rho \cdot q \cdot g \cdot H_{\text{gross}} \cdot \beta \cdot \eta \]  

where \( P \) is the turbine power, measured in W, \( q \) is the volumetric flow rate, given in m\(^3\)/s, \( \rho \) is the density of water (\( \approx 1000 \) kg/m\(^3\)), \( g \) is the gravitational constant (\( \approx 9.81 \) m/s\(^2\)), \( H_{\text{gross}} \) is the gross hydraulic head, \( \beta \) is a factor accounting for the losses along the pipeline, and \( \eta \) the product of the efficiencies of turbine, drive system and electric generator. A similar equation applies for the power of storing energy in the PHES

\[ P^* = \rho \cdot q^* \cdot g \cdot H_{\text{gross}} \cdot \beta^* \cdot \eta^* \]  

Where \( P^* \) is now the pump power, measured in W, and \( \eta^* \) the product of the efficiencies of the pump, drive system

and electric motor. The energy that may be stored is then proportional to the volume of the reservoir to fill/empty, or even better the mass of water available to be moved from one reservoir to the other.

The round-trip efficiency is simply:

\[ \left( \frac{\beta^* \cdot \beta \cdot \eta}{\eta^*} \right) \]  

As the volume of water pumped up \( q^* \Delta t^* \) usually exceeds the volume of water moving down through the turbine \( q \Delta t \) because of the inevitable losses (eg, evaporation, or filtration),
the above round-trip efficiency should be corrected for this loss. Natural replenishment of the upstream reservoir is obviously helpful in improving the operation of the facility. Clearly, the potentially the best locations are areas with a large hydraulic head and the opportunity to build reservoirs with limited losses and potentially much larger catchment of water.

The practical determination of the round-trip efficiency all-inclusive is everything but trivial. In cases for example such as Tumut 3, where the upstream reservoir is also naturally filled, and similarly, the downstream reservoir is also partially empty through discharge, the round-trip efficiency may largely differ from the simple efficiency ratio $\eta$. With round trip efficiencies of 70%-80%, 20%-30% of the wind and solar energy stored by PHES is lost. Additionally, in a mostly arid, flat, and scarcely populated country, only minimally covered by a grid, the good sites for PHES, apart from the existing hydro gravity locations, are limited.

7 | NEM ENERGY STORAGE

Based on the 5% minimum capacity factor of Figure 2, without energy storage, the nominal capacity of wind should increase up to 20 times the NEM capacity, to make possible a fully renewable energy grid free of any direct carbon dioxide emission. However, not only sometimes the actual wind energy power generation falls below 5% of the nominal capacity, sometimes it goes up to above 60%. This way, a huge amount of wind energy generated in excess, in every other time apart from the minimums, would be lost. Worth to mention, with the one-minute resolution, it may become clear that even a nominal capacity that is 20 times the NEM capacity may be inadequate, as the capacity factor may easily fail even below 5%, despite the wind farms are widespread across one half of Australia, and similarly the capacity factors may go well above 60%. Additionally, without any storage facility, almost all the solar energy, Figure 3, would be similarly lost. This simple analysis clearly shows how needed is energy storage for a grid without combustion fuels.

Significant energy storage is needed to make possible a fully renewable energy grid. Without dramatically oversizing the nominal capacity of wind and solar, energy storage of power the total peak power of the grid and energy this power multiplied by at least a couple of days, would be requested to balance a NEM grid feed by wind and solar energy only, plus the small hydroelectric contribution.

The present battery energy storage of Australia is less than 200 MW power and 200 MWh energy, despite including the 100 MW/129 MWh “world largest” battery. The present battery energy storage technology is lithium-ion batteries. Neglecting the fact that the lithium-ion batteries, despite free of the memory effect of nickel-cadmium batteries, cannot be fully discharged to ensure a long life (the best way of increasing the number of charging cycles is by charging between less than full and more than empty), for balance between battery life and workable capacity, the energy that can be presently stored, can be only discharged at 200 MW rate for less than 1 hour, in practice only 30 minutes.

PHES is considered very promising down-under. Presently, the PHES facilities are the previously mentioned 500 MW Wivenhoe Power Station, and the 1500/600 MW Tumut 3 Power Station. As previously written, presently, the peak power capability of the NEM is 46 848 MW. Hence, also converting to pumped hydro all the existing hydro facilities, with pumps’ power same of turbines’ power, the storage capability is already inadequate in terms of capacity.

The 1500 MW Tumut 3 hydropower station is part of the Snowy Mountains Scheme, also consisting, in addition to Tumut 1 and Tumut 2, of four other major hydropower stations, Murray 1, Murray 2, Guthega, Blowering, plus 2 small hydropower stations recently constructed, Jindabyne Mini Hydro, and Jounama Small Hydro. The total 33 turbines have a total generating capacity of 4.1 GW according to Reference 7 producing the highly desirable renewable power-on-demand even without pumping. The NEM registered capacity is less but still large. The pumping stations of the Snowy Mountains Scheme are a small one at Jindabyne and a much larger one at Tumut 3. In the Tumut 3 power station, three of the six turbines can also work as pumps. The power of the pumps, as previously written, is 600 MW. The pumped hydro capability of the Tumut 3 facility is much less than the 1800 MW claimed by Wikipedia or the 1650 MW of Reference 23.

Hydro–Gravity facilities already supply power-on-demand. By adding pumping capabilities, the amount of power-on-demand may certainly increase, depending however on the profitability of the recharge of the upstream reservoir (presently, the hydro gravity facilities of Australia produce much less electricity than 20 years ago simply because the focus on peak power is more rewarding than the focus on baseload). While it has been proposed to modify the most of the existing hydro gravity power stations with pumping capabilities, and this will certainly give a considerable improvement of storage capabilities, as additional good hydro gravity locations are limited (Australia is mostly arid and flat), other PHES facilities will have to be developed along the coast in proximity of the transmission lines.

There is a significant difference in between the power of the energy storage needed and what is presently available, and an even larger difference between the storable energy needed, and what is presently available. Increasing the installed capacity of wind, solar, and solar rooftop to cover the total peak demand, up from the present values, is much easier than to increase the storage capacity from the present
values to what is needed. Again, to consider, most of the Australian land is off-grid, flat, and arid.

8 | ELECTRICITY AND TOTAL PRIMARY ENERGY SUPPLY

Another aspect to consider in this analysis is that the Total primary energy supply (TPES) largely exceeds the electricity. The TPES of all of Australia, also including Western Australia and the Northern Territory, of 2016, was 129 752-kt of oil equivalent (ktoe), corresponding to 1 509 016 GWh. The electricity generation of all of Australia in 2016 was 256 563 GWh. It does not make any sense to make fully renewable the electricity grid, removing any energy supply from combustion fuels, and then use combustion fuels to cover the other energy needs, for example for transport. To cover all the TPES needs by wind and solar, plus the small hydro, through electricity, this would need an even much larger installed capacity of wind and solar, and an even more unrealistically large energy storage.

Not included in this analysis are additional issues, for example for the transport uses of electricity, the limited range of battery electric vehicles, coupled to the lack of any recharging infrastructure in a scarcely populated country where over 66% of the population lives in the greater metropolitan area of eight capital cities, and the remaining less than 34% of the population is spread out in the countryside with a density of about one person every square kilometer.

While superficial claims may support the view of reduced energy costs of running electric vs combustion fuel vehicles, these claims neglect the fact that the life cycle analyses of electric and traditional vehicles do not show any advantage of the electric mobility. Construction of electric vehicles is much more energy-intensive. The recharging infrastructure is nowhere to be seen, and it is hard to expect a widespread recharging infrastructure will cover all of Australia within this century when most of the Australian land is still off-grid. Disposal of electric vehicles is also more expensive. The range of electric vehicles is inadequate for scarcely populated areas of less than one person per square km. Electric vehicles are also much heavier and have a drastically reduced payload, vs conventional vehicles. Also, considering the limited availability of the material needed for the batteries, the electric mobility is harder to become a reality shared by the masses.

9 | CONSUMERS PRICES AND WIND AND SOLAR SHARE OF ELECTRICITY

Wind and solar supply intermittent energy to the electricity grid. They are considered as every other power generation facility, but they only supply power that cannot be guaranteed. Without a dedicated energy storage facility, a wind or a solar facility cannot guarantee any given production. Every power generation facility willing to sell power into the grid, the NEM, must guarantee a minimum level of supply 24/7, with that minimum level not lower than 80% of the maximum level. The rule does not apply to the single facility, but to the different facilities of the same operator, that must guarantee a total minimum level of supply 24/7, that is not lower than 80% of the total maximum level. Without energy storage facilities in the portfolio, fossil fuel power plants inefficiently working intermittently to compensate the intermittent share by renewables, are needed.

Without energy storage, a wind farm needs a backup fossil fuel power plant of the same capacity, as sometimes the capacity factors go to zero, and some other times to 100%. Similarly, without energy storage, a solar photovoltaic facility also needs a backup fossil fuel power plant of same summer solstice capacity, as the production goes to zero every night. Right now, two power stations are needed to cover the job previously covered by one single power station, the fossil fuel power stations producing electricity on demand, and the wind and solar power station, producing electricity depending on the weather and the daylight. This is the reason consumers have paid about 10 c/kWh for about two decades up to 2007 when the wind and solar renewable energy supply to the grid was zero. Then, the prices started to rise dramatically, already 25 c/kWh in 2013 (250% increment in 6 years). Since 2013, prices have increased even more, with real-world retail prices approaching, and often surpassing, the 40 c/kWh.

There is no reliable statistic of electricity prices in Australia since several years, as the electricity market is characterized by many different offers by many different providers, also changing with many variables, from the post-code, to the type of meter, from the payment by direct debit or credit card, to a contract for electricity only or electricity and gas with same provider. Data of individual electricity bills, such as the one of Figure 6A, report Peak usage 41.943 c/kWh (Peak time is 7 AM to 11 PM), Off-Peak usage 22.22 c/kWh and Supply charge 144.122 c/Day. It is, therefore, reasonable to update the graph of Reference 25 reporting the prices up to 2013, when the market offer was much more limited and uniform, with a present cost of 40 c/kWh, as it is done in Figure 6B. The prices up to 2013 are 2012 $ values for NSW residential electricity customers. This graph does not include the temporary stable prices that were experienced during the short Abbot government (September 8, 2013 to September 14, 2015) after repelling of the carbon tax. According to Reference 25, the projected price of electricity by 2020 was 26 c/kWh.
In the fiscal year 2017-2018, the contribution of the intermittent wind and solar photovoltaic was still only 5.74% and 3.80%, with the help of a reliable and dispatchable hydro contribution of 6.07%. As shown in Figure 6C the renewable energy contribution in Australia was about 10% Hydro and 0.5% of the biomass in 1990. In 2010, it was about 6% Hydro, 0.8% Biomass, 2.4% Wind and 0.6% Solar. In the latest available fiscal year, 2017-2018, it is 6% Hydro, 1.5% Biomass, 5.7% Wind, and 3.8% Solar. Geothermal has always been insignificant.

The remarkable growth of Wind and Solar is partially balanced by the drastic reduction of Hydro. This reduction is simply the result of the wholesale pricing of electricity in Australia. The NEM is indeed a wholesale market where a multitude of “generators” sell electricity and an even larger number of “retailers” buy electricity. With wholesale spot prices in times of higher demand of about 14 $/kWh compared to an average of about 10 c/kWh, the maximum profit of Hydro generation is decoupled from maximum production.

10 | DISCUSSION AND CONCLUSIONS

The contribution supplies a unique high frequency (3 minutes interval) description of the wind and solar energy supply to a large grid and compares this supply to the total energy demand. The contribution highlights the relevance of energy storage, as without, the grid must rely heavily on the combustion fuels energy supply to compensate for the intermittent and unpredictable wind and solar energy supply, and to avoid renewable energy being wasted, can accept the further increment of solar and wind capacity only up to the point their instantaneous annual maximum become equal to the instantaneous annual minimum in the demand. Hydro gravity facilities already supply power on demand to the grid. While they may be upgraded with pumping capabilities to serve as energy storage facilities, other facilities, both new coastlines pumped hydro and battery must be developed.

As Australia is nominally a free market for energy but controlled by the government through rules, burdens, and subsidies, the only cost that can be discussed is the cost of electricity to consumers. Recently the government has been focused on the reduction of costs through pressure on the energy retailer, that have grown in number dramatically n recent years also dramatically increasing their profitability. This action that is now reducing the energy bills is not related to the construction of some facilities or the shutdown of other facilities.

There is a perfect correlation between the addition of wind and solar energy from Reference 26 and the increment of consumers’ prices of electricity from Reference 25 covering up to 2013. This is the result of not having planned for energy storage and not having acknowledged the intermittency of wind and solar energy supply to a grid that must be balanced at any time to operate.

Energy storage research and development should be the top priority of any government really interested in energy supply free of combustion fuels. Serious attempt to make an electricity grid fully renewable wind and solar photovoltaic should acknowledge the energy storage issue and try resolving this fundamental aspect before planning to completely phase out the combustion fuels energy supply.

If you want a fully renewable energy grid, then the energy storage problem must be addressed. As not only the electricity needs, but all the needs of TPES should be renewable to make sense, the amount of energy storage by batteries and pumped hydro must become extremely large, and
the grid must be expanded to cover all of Australia. Such an achievement is hard to be forecasted within a brief period.

While battery technologies have certainly evolved, and are further improving, the sought technological breakthroughs in battery technologies are still missing. Considering the environmental and economic costs to build and dispose of the present technology lithium-ion batteries, the shortage of the raw materials needed, additional to their unethical mining, and relevant to the transport application, also the low volumetric, and mass, energy density, the battery issues need to be solved sooner the better, because, otherwise, there would be, not environmentally, nor economically friendly, renewable energy grids, electric mobility, and other primary energy uses of wind and solar.

For what concerns energy storage for the grid, pumped hydro is apparently the best way to go, and upgrade of the existing hydro gravity facilities with pumping capabilities is certainly the opportunity to build a large energy storage capacity within a brief time frame. Added PHES facilities will have to be found along the coast close to the grid lines. It must be remembered that Australia is a scarcely populated country, mostly arid and flat, with very few rivers, having a grid that is currently covering only a small part of the available land. Hence, the PHES potential in the interior is extremely limited. Thus, PHES are part of the energy storage solution, but not the only solution.

Proposals of PHES facilities almost everywhere, such as References 35 and 36, including unsuitable places where there is no water, there is no large hydraulic head, there is no grid, there are no wind or solar farms to stabilize, there are no peoples, there are no roads, and there are no electricity end-users, are misleading. The expansion of PHES is less simple than what is told to the press. There are not too many places in the interior of Australia where it is possible to build PHES, the same of many other areas of the world suffering from water scarcity. Proposals of PHES facilities in the Simpson Desert in Australia, same of the Sahara Desert in Africa, do not make too much sense.

The coastline, saltwater, PHES are certainly more practicable, but still posing significant technical difficulties. As a matter of facts, seawater PHES is still in their infancy, with many other challenges compared to freshwater PHES. Apart from the 240 MW old tidal power station of La Rance, France, completed in 1966, that can partially work as PHES, but is not exactly a coastal gravity PHES as those now being considered, there has been only one demonstration project conducted worldwide that is worthy of mention, the 30 MW Yanbaru station in Japan, completed in 1999 but already decommissioned. Thus, seawater PHES may certainly be interesting, but it has still to be proven it works efficiently at acceptable costs, still lacking real-world plants completed and operated.

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