Existing and Future Electrical Supply Challenges

Anthony Rudland Kjar
Managing Director
Gibson Crest, Sydney, Australia
Corresponding author: arkjar@bigpond.com
https://doi.org/10.71659/icsoba2025-al069

Abstract

Most large countries will change their existing electricity generation to reflect existing generation characteristics and in response to growth and a reduction of carbon gaseous emissions. Country and company responses will not be uniform in time and nature. To some extent it will also be dependent on new and improved technologies. Electrical generation is likely to increase dramatically. Some existing generation will be shut or expanded, and new generation may be developed to generate to power electric vehicles and hydrogen for new heat sources and process chemicals. As part of this change there will be increased generation using limited time of day renewables. Some generation will be for direct use and a faster growth for power storage systems. There will be major changes in electrical grids to increase connectivity and conductivity between remote generation and customer loads as well as how sparing is provided. The size of smelters, management of demand, grids, sparing contracts as well as the determination of price will also change so as to overcome the increasing complexity of generation types, operating and capital cost structures, periods of supply and sharing of risk. There will also be a need to change the electrical market(s) to reflect changes in timing of new installations, differences in old market structures that evolved of a long period of time and ranking by operating cost and short period bidding and new markets, which need to evolve rapidly and are dominated by long periods of supply and capital costs. New markets structures are proposed. Aluminium is currently the largest electrical base load in most large producing countries. The key issues covered in the paper include comparisons between China and Australia.

Keywords: Electrical generation, Grids, Markets, Costs.

1. Present

1.1 Electrical Generation

Electricity underpins most residential, commercial process industries and services within all modern economies. Currently, one-third of global electricity generated (kWh), but a lot less of the total energy comes from low carbon sources [1-4] and is outlined in Figure 1.

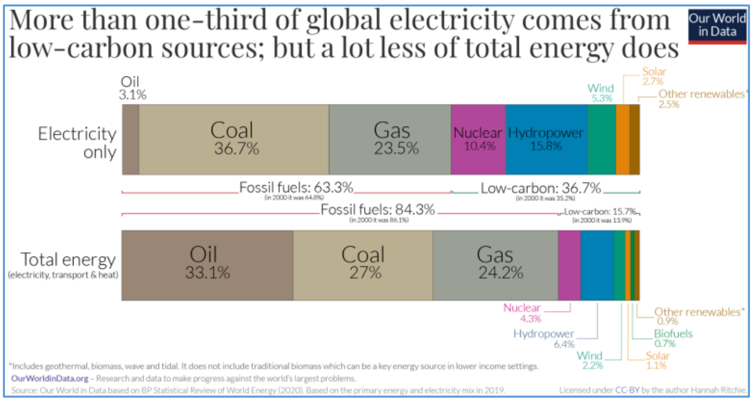


Figure 1. Global electricity and total energy.

It is useful to focus initially on the generation of electricity, then examine how this might change as decarbonization occurs when some total energy is generated by renewables. Individual fuel sources of global electricity generation per capita [2] are shown in Figure 2.

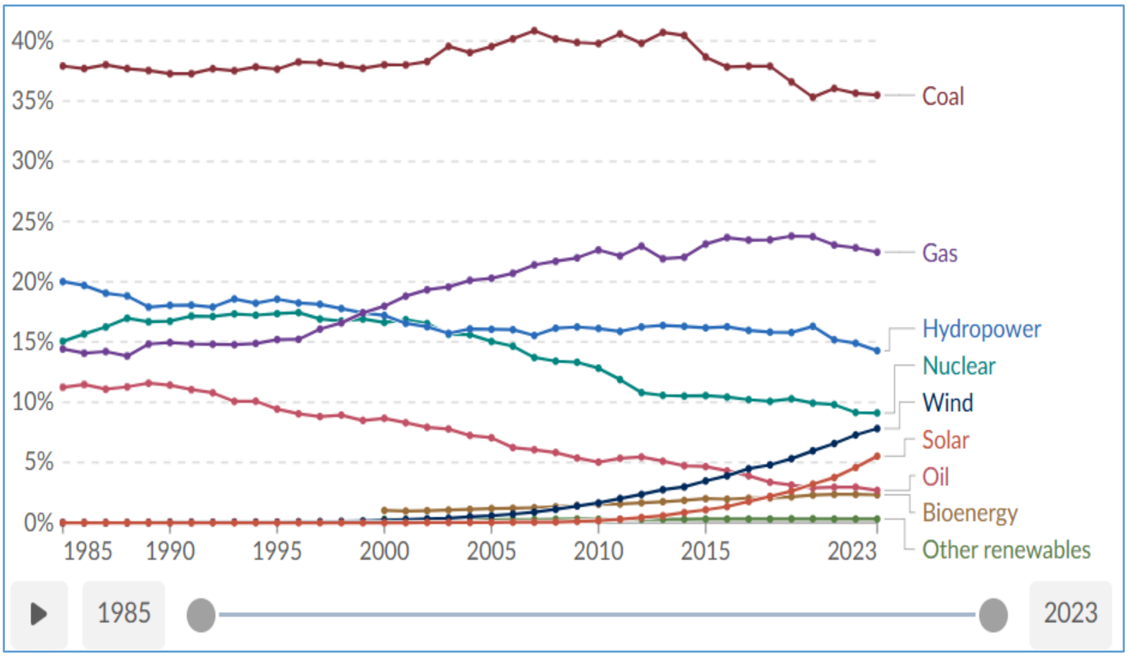


Figure 2. Fuel sources for global electrical generation [2].

Overall, the consumption of coal is declining, but in some countries such as China it continues to grow. The present electricity generation by source [2] is shown in Figure 3.

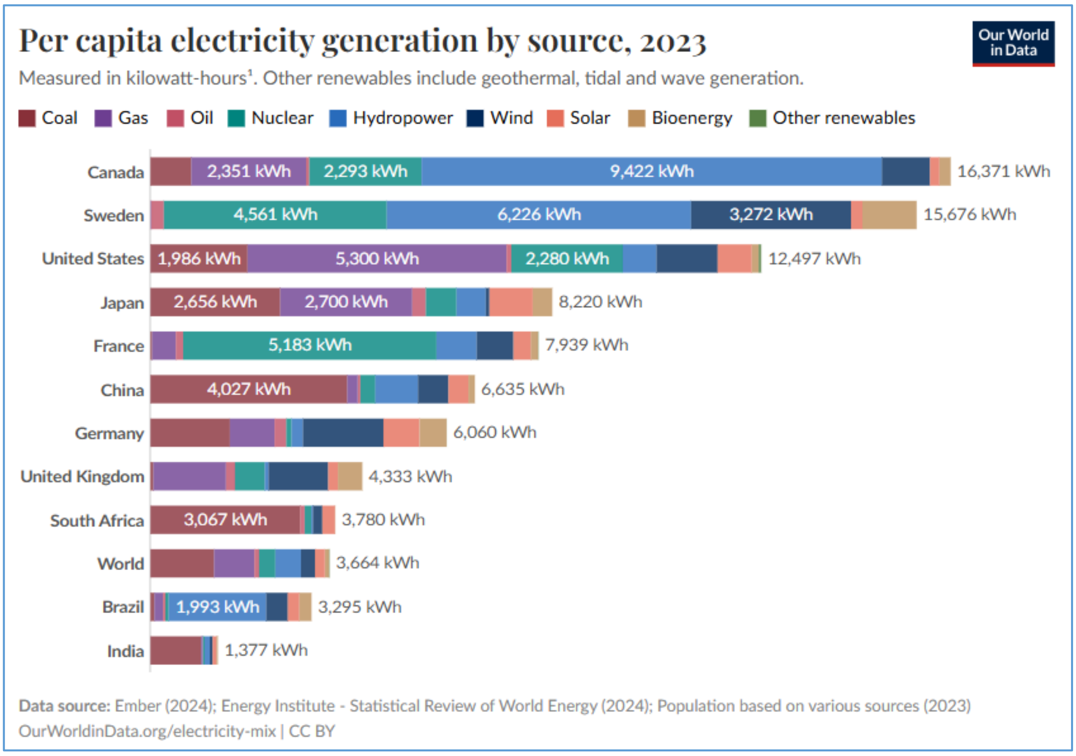


Figure 3. Per capita electricity generation by source [2].

A ranking of highest coal consumption per capita of countries product, as calculated from Figure 3, is shown in Table 1.

Table 1. Ranking by coal consumption per capita.

Country/%	Coal	Gas	Oil	Nuclear	Hydro	Wind	Solar	Other
South Africa	85.5 **B**	0.8	2.3	5.1	0.8	2.9	2.5	
India	70.5 **B**	3.9	0.1	3.3	12.1	4.5	4.4	1.1
China	60.7 **B**	3.3	2.1	4.8	17.8	6.1	3.4	1.7
Australia	53.7 **B**	3.0		0	6.4	13.4	23.2*	0.4
World av.	33.9 **B**	22.8	4.4	10.1	16.8	6.1	3.2	2.7
Germany	33.7 **B**	14.7	0	11.9	3.2	19.9	8.8	8.5
Japan	29 **B**	31.2 **B**	8.7	4.6	9.3	1.1	9	7.1
USA	19.1	40.2 **B**		19.5	7.0	8.3	3.2	1.7
Canada	7.0	8.9	0.8	14.8	60.8 **B**	5.3	0.7	1.6
Brazil	3.6	8.6	1.4	2.2	64.6 **B**	9.4	1.2	9.0
UK	1.9	40.1 **B**	2.8	15.3	1.8	21.1	4.1	12.8
France	1.1	1.9	1.9	69 **B**	10.7	6.7	2.6	1.7

Legend **B** = Base load. * Includes Roof Top and Solar Farms

In the next 35 years, it is likely that most countries will replace coal emissions with less carbon dioxide intensive emissions. A relative magnitude of this initial task can be compared by calculating the required reduction in coal carbon fuels per year based on the Paris Agreement commitments [5-6]. Approximations on the magnitude of the year tasks are shown in Table 2.

Table 2. Rate of change needed to achieve zero carbon for existing electricity generation.

	China	Australia
Coal use in generation	60.7 %	53.7 %
Timing of coal reduction	2023 to 2060	2023 to 2035
Reduction rate	60.7 % x 100% / 37 years = 1.6 %/year	53.7 % x 80 % / 12 years = 3.6 %/year

1.2 Decarbonisation

Each country will also require additional electricity to decarbonize fuels used in engines (cars, trucks, ships, aircrafts, static engines) and provide heat sources used in process industries. These changes will have a substantive impact on electrical supply, requiring a doubling or tripling of the current generation. This challenge will be limited by the development of cost-competitive production of additional electricity, hydrogen or its derivatives, heat pumps, carbon capture and storage and improvements in the particular processes for green hydrogen, steel, cement, aviation fuels, and electric vehicles. Continuing developments include the lowering of costs in solar and wind generation as well as batteries. Batteries are also used to provide key grid services such as inertia and system strength as well as some storage.

1.3 Driving Forces for Change

The driving force for change has been the threat of global warming arising from the increase in greenhouse gases in the upper atmosphere, principally from carbon dioxide and methane. The trends in annual emissions of carbon dioxide are shown in Figure 4 [5].

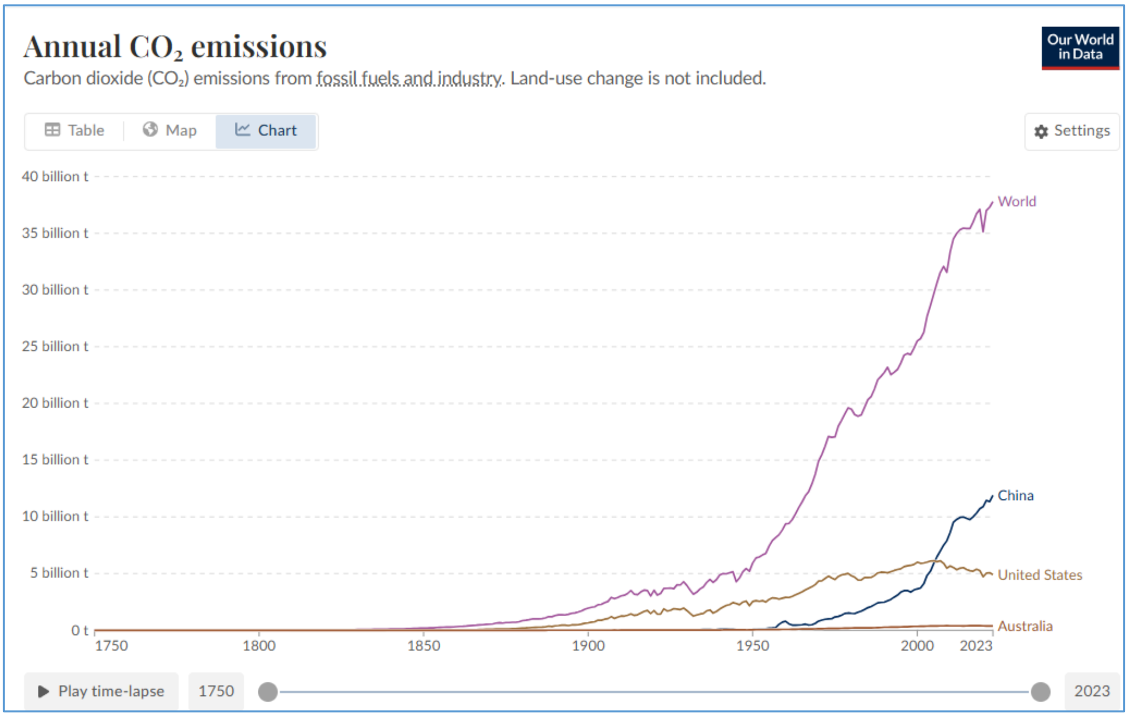


Figure 4. Annual carbon dioxide emissions [5].

The United Nations has coordinated a global response, starting with the Paris Agreement COP 15 and subsequent adoption of various global targets and strategies.

China has committed to be at peak carbon by 2030 and carbon neutral by 2060. China has issued a plan to strengthen its energy storage sector, aiming to develop more "leading manufacture, improve innovation and increase world competitiveness by 2027. The policy will also support research into emerging technologies, such as alternative battery compositions and compressed air and hydrogen storage systems". These commitments are known as "China's dual carbon goal." [6].

Australia has agreed to an emissions reduction of 43 % below 2005 levels by 2030, 80 % by 2035 and net zero by 2050, with some States having more aggressive targets [7, 8].

However, these drivers are losing some of their momentum. China, along with 181 other countries, missed a deadline to submit their "nationally determined contributions", a key 2035 Climate pledge to the UN [9,10]. In addition, USA and India are not now included in the COP program. Currently China, India and USA make up at least 53 % of energy emissions. Nevertheless, it is likely that most nations will continue with some major energy changes, driven by other global constraints and incentives, but with a longer transition period.

2. Increase in Renewables

2.1 Present Generation

2.1.1 Coal Generation

Present total and coal generation is described in Table 3.

Table 3. Coal generation comparisons.

	China [11, 12]	Australia
Total installed capacity 2025	3600 GW	Approx. 80 GW
Present total generation	8500 TWh	250 TWh
Total installed coal capacity 2025	2000 GW approx.	21 GW in Eastern Australia
Coal consumption increase per year	+1 %	-5 %
Coal fired stations	1300	17
Utilization rate	48 to 49 %	75 %
Largest turndown ratio	30 %	20 %
Best Boiler Technology	Many large High Efficiency Low Emissions (HELE) super critical pressure	4 super critical pressure
Permitting	Continuing	Planned shutdown

2.1.2 Renewable Generation

Present renewable generation is described in Table 4.

Tabel 4. Renewable comparisons.

	China [14-17]	Australia [13, 14]
Annual solar percentage 2013 to 2023	42 %	22 %
Size of solar part 2029	609 GW	33 GW
Solar percentage of total generation	3.8	11.7
Base load after removal of coal from the present totals in Table 1	22.6 % (hydro plus nuclear)	6.4 % (hydro)
Scale of solar and wind	Very large, e.g., Gonghe Tulatan Solar Park is 8.4 GW and increasing	1 GW is a typical size
Solar and wind battery storage	NA	1, 2, 4 and 8 hours (planned)
Solar battery coupling	NA	AC and DC coupled

Of all countries, China faces the largest task to meet their COP15 Paris commitments. However, Australia, already with a large roof top solar component, but a small base load component of hydro and nuclear, faces the most challenging task. This includes integrating the intermittent renewables into the system quickly, overcoming significant challenges in instability and shortages with a very low base load generation after coal is removed, and having a low turn down ratio for the total coal fired boiler capacity for coal fired boilers.

2.2 Generation Trends in China

The State Corp monopoly was disbanded in Dec. 2002, and 11 smaller companies were established. The 5 largest have almost 10 % each of the national installed capacity, with their listed subsidiaries having an extra 4 to 5 % each [11,12]. Control is through regulation and developments by the provinces and village companies, directed mainly at job creation. China is the world's largest emitter, and about 75 % of its emissions come from coal. Despite China's central role in the coal transition, few studies have explored its overall approach to addressing the associated socioeconomic issues [18].

2.3 Generation Trends in Australia

The Australian approach is driven by an ideology to eliminate coal and gas as quickly as possible. It has been assumed that aging power stations would shut first, due to unreliability. This assumption can be questioned, as the reliability has not been due to aging, but is due to poor maintenance and insufficient preventative maintenance. Maybe a better order of shutdown of stations should be based on the future highest cost of coal per kWh, as this would lower emissions and power prices in the near future.

A world first large-scale battery (100 MW) was installed at Hornsdale in South Australia in 2017.

The rapid acceptance of roof top solar by individual consumers has been remarkable. This change has been assisted by government support. The next challenge is to strengthen output with localized batteries and tie it in with new electrical demand and supply from electrical vehicles (EV) as well as replace gas in consumer electrical equipment.

While initial solar and wind farms have progressed, together with increasing the grid inter connectivity, these developments are being slowed by a loss of social license and an inability to substantially lower power and grid prices.

3. Grid Changes

3.1 Present Grids

The present grid characteristics are shown in Table 5.

Table 5. Comparison of grid characteristics.

	China [19, 20]	Australia [21-25].
High voltages, kV	800, 500, 330, 220	500, 275
Main Provinces/States	East, Central, North East, North, South.	QLD, NSW, Victoria.
Control	Central	AEMO coordinated, but major input and constraints by States and Federal governments.
Backbone	Circular, interconnected, with High Voltage Direct Current links.	Linear. 13 000 km long.
Based on	Huge coal resources.	Local export coal resources, with lower grades used initially for power generation.
Cost of strengthening the main grid and installing interconnections with new generating zones.	800 GUSD by 2030.	77 GUSD by 2030.
Load centres	Industrial regions and population centres.	Industrial plants and population centres.

3.2 Grid Trends in China

The two main synchronous generation grids in China are the State Grid in the north and the Southern Grid in the south. The challenge is to integrate these grids with many provincial and regional grids.

3.3 Grid Trends in Australia

The Eastern Australian Grid, managed by the National Energy Market (NEM) and coordinated by the Australian Energy Market Operator (AEMO), is reputed to be the longest in the world. However, this grid is narrow and limited in capacity. There are many players within the states, federal government and private companies, limiting the rate of integration. Upgrading the grids is on the critical path for decarbonization.

4. Market Structure

4.1 Present Structure

A comparison of present market structures is shown in Table 6.

Table 6. Present market structures.

	China [26-31] [34]	Australia [32–33]
	National Unified Market from end of 2025.	National Energy Market (NEM)
Electricity sales	Regulated rates.	High prices and spikes.
Coal supply	Major State-owned Enterprises on regulated contracts.	Most coal pricing is set relative to international prices.
Separation of grid and generation	Starting.	Well established.
Separation of wholesale and retail markets.	Regulated, but can be varied.	Yes. Regulated retail pricing.
Prices	Regulated coal-based generation. Renewables bid a fixed price determined by auction. Cheaper than coal.	All types bid on 5-minute repricing frequency. Also, the cost of coal is not stable. At present it is determined by stranded brown coal in Victoria and alternative internationally priced coal in other states. .
Individual electricity producers	11 in country, with 5 large ones	Many, including governments.
Conflict between solar and coal in the middle of the day	Quotas force utility companies to buy coal fired power over cheaper renewables. In a major policy shift towards market liberalization, contract for difference auctions for renewable plants and removal of energy storage mandates.	Considerable, as solar increases and coal decreases. Coal fired power plants have little turndown, and lower prices to negative levels so as to continue to operate.
Contracts	Some Contracts for Difference.	Long Term Energy Service Agreement with states to provide firm capacity. Various contracts for Difference, plus Power Purchase Agreements, which have risks.
Transparency	Published regulations.	Little. There are many different contracts, for different forms of electricity, each with different conditions and within the same Market.

4.2 China's Market Transition

China is actively reforming its electricity pricing mechanism, particularly for renewable energy with a move towards market-based prices [31]. The National Development and Reform

Commission introduced an overall electricity model in 2023, based on the premise of "Cost plus a reasonable profit."

The new market resembles the two-way Contracts for Difference mechanism used in the UK and elsewhere [33].

Despite some reports to the contrary, the move does not constitute a roll back for renewables [30]. Grid operators have been paid wind and solar generation the same price as for coal-fired power since 2021. The change to the rules has been attributed to the sharp reduction in cost of building new solar and wind farms.

The coal-fired grid benchmark was last updated in 2017 and actually has no relationship to the generation cost of renewables. At the same time, coal-fired power plants are continuing to receive policy and financial support, in the form of guaranteed demand from long term contracts and compensation to keep excess capacity online.

The exact impact that this will have on renewable developers will depend on implementing the rules adopted by local government. In the short term these companies will be hit by a loss of guaranteed demand and the need to adopt low prices and fierce competition. If coal plants are not also exposed to competition, the renewables may be crowded out from the power market. However, China's carbon peaking sets a hard deadline for reducing their role in the power system. At the same time, the Chinese government relies on coal power to ensure energy security when hydro power output drops as a result of insufficient rain.

4.3 Australia's Market Transition

The NEM is managed through a collection of State and Federal controls. Supply of power comes from a mix of private, State and Federal facilities.

The market has evolved from State markets based on five-minute bids of order of merit cash cost dispatch models for continuous power generation. At present there is no inventory, with prices determined by supply and demand, leading to very high prices in times of shortage. The cash cost bids came from a range of similar generators that have a wide range of older similar facilities. There are also bids for gas fired, hydro and renewable facilities, with a range of storage facilities. In time the complex conditions with the inclusions of subsidies and differing time periods of generation have evolved.

Limited interconnectivity between states, the lack of an inventory, and the shut of coal fired stations affect prices.

There have been a range of proposals to improve the market mechanism over recent years. This has included subsidies for renewables. All are based on having one pool of electricity within one market, although some large customers have Power Purchase Agreements with retailers or government suppliers.

Millard [26] notes:

" *a common issue with the introduction of wind and solar farms is the wasting of energy at rising rates by stopping of production because there is not enough capacity to transport and store electricity when demand is not enough to use it straight away. This also occurs in a range of other countries.*

The waste is a result of the mismatch between the rapid roll out of weather dependent wind and solar farms and the slower installation of power lines to move the electricity around, as well as the shortage of storage through batteries and larger methods such as pumped hydro. This is reflected in increasingly volatile short term electricity prices, with inter-day prices rolling between negative and extreme highs in some markets in the past years.

Prices have turned negative during particularly windy or summer periods, as generators in effect pay consumers or owners of storage systems to take electricity off their hands.

While the wind and sun are free, and some level of wastage is to be expected, volatile prices can be costly for all developers and consumers. Also, the surge of these intermittent sources of energy brings greater difficulty in the matching electrical supply and demand on a second by second basis so as to maintain system stability."

The latest change to the Capacity Investment Scheme (CIS) is to encourage some form of readily dispatchable power [35-37]. Under the CIS, auctions set the terms of engagement - the underwriting and maximum price. At present these auctions are based on a Contract for Difference approach, where the developer is guaranteed a floor price. In many cases the State is taking some or all the risk of low prices in the pool, while both share in the high prices. This type of financial derivative is not acceptable in some parts of the world, due to its high risk.

In addition, one commentator [34] notes that the CIS is not a "capacity scheme" at all, because capacity mechanisms are supposed to cover plants the generate power on demand, rather than weather dependent renewables. It is not connected to meeting any mathematical way a particular level of reliability or response adequacy. Only 9 of 32 GW will support dispatchable capacity. CIS does not address the replacement of coal power plants.

Another emerging issue under investigation [38] is whether the grid is fit for purpose for a renewables dominated grid is now proceeding. Issues emerging are the length of contracts signed by the utility with wind, solar and storage projects, consumer energy resources (roof top solar, battery and electric vehicle charging).

A more recent change to the CIS is to set a National Renewable Energy priority list that has been agreed with the States and Federal Government. The inaugural list updates 56 priorities for solar, battery transmission projects [39]. This will enable coordinated support for regulatory planning and environmental approvals. The success of these initiatives will only be apparent over the short term if investors and the banks are prepared to finance the developments and whether the power pricing is attractive over the longer term.

However, none of these changes address the issue that it is sensible to link energy supply to the needs of 24-hour 7 days per week and 365 days per year customers, such as process industries like smelting, hydrogen production, data centres and services. For these types of customers there is a strong link between type of customer and generator technology.

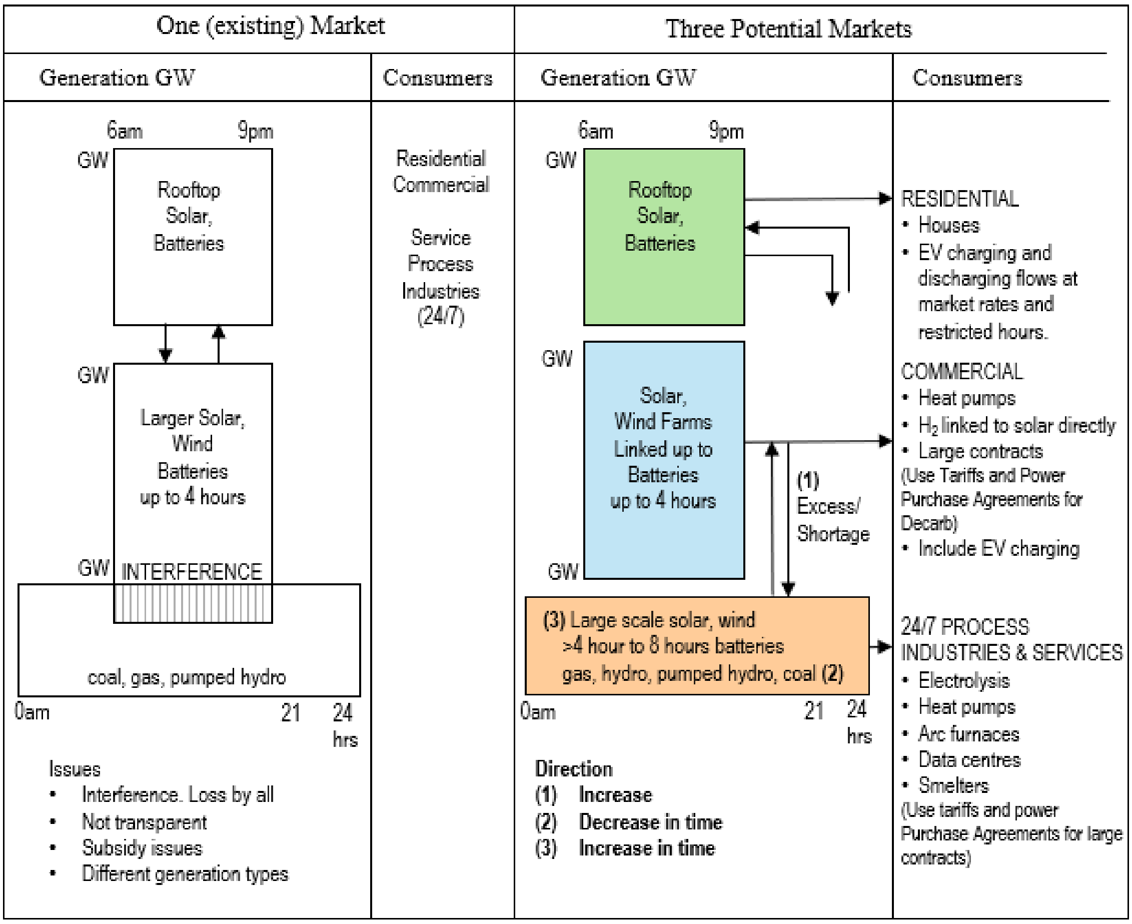
The broad customer market can be split by demand periods of the day of peak demand (approximately 6 am to 9 pm) for Residential, Commercial and 24 hours per day Process and Services Industries.

Splitting the single market into three will free up midday constraints imposed by a clash of solar with coal fired power generation. This allows the strategy and operation of each market to be optimized around delivery, reliability, cost and pricing targeted to be internationally competitive. It will also allow a focus on strategies for achieving the required storages and time for each market to cover shorter term fluctuations and longer-term climate issues such as drought and storms.

This lines up reasonably well against average hours for renewables from roof top solar and large-scale renewables and continuous supply from coal, hydro, longer term batteries and other storage methods.

It would appear sensible to separate the one complex market into three aligned markets as shown in Table 7.

Table 7. Possible three potential market strategies.



5. Aluminium and other 24/7 Markets

5.1 Present Aluminium Market Comparisons are Shown in Table 8.

Table 8. Aluminium market comparison.

	China	Australia
Production	41 Mt/y	1.5 Mt/y
Smelters	Approx. 100	4
Smelters greater than 500 kt/y	18	2
Energy source power coal/hydro	Overall grid the ratio is high. New smelters are being limited and have been built in Eastern China and Northern China based on hydro and nuclear	88 %

5.2 Sparing

Few, if any smelters are directly connected to a power source, without some strong backup in loss of power supply for an hour or more. There is a history of power failures from a variety of reasons that involve operations and weather-related issues [40].

With the increasing size of smelters, matched with the use of large Power Purchase Agreements for renewable based power supply, it will become increasingly important to develop strong back up arrangements.

6. Aluminium and other 24/7 Markets

Coal will form an important part of many power systems until China, USA and India reduce consumption significantly.

It is unlikely that the present levels of internationally competitive reliable electricity for many process industries and services will be able to survive this change, unless special attention is focused on the transition and advantage is taken on emerging technologies, most of which are capital based.

Relevant to the aluminium industry, these technologies and work practices include:

(1) Electrolysis and materials selection for aluminium, steel, batteries, and hydrogen processes.
(2) Internationally competitive 24/7 power and adequate sparing, within a specific market structure.
(3) Major reductions of capital costs of smelters, power plants and process materials, including replication, defining and controlling scope, management of the capital process as capital considerations will define the future.
(4) Carbon capture and storage for some process elements.
(5) Nature and role on nuclear electrical generation.
(6) AI for process control, automation and robots.
(7) Major improvements in demand and sparing management.
(8) Mandated specific energy consumption for smelters.
(9) A major increase in recycling.

7. References

1. *Our World in Data*, https://ourworldindata/energy-production-consumption.
2. Ember, *Statistical Review of World Energy,* 2024.
3. *BP Statistical review of world energy*, https://www.bp.com 2022.
4. *IEA World Energy Outlook, 2024*.
5. *Our World in Data, Global Carbon Budget,* https://ourworldindata.org/explorers/CO2??country. 2024.
6. *COP commitments China,* https://www.google.com.au.
7. *COP commitments Australia*, https://www.google.com.au.
8. AOFI, *Australian Government Climate Change*, Nov. 2022.
9. Anika Patel, Missed climate deadline, China-tech's economic contribution, *New Renewables Policy,* 21 Feb. 2025.
10. Anika Patel, China missed 2024 targets, *Carbon Brief*, 7 March 2023.
11. China Installed capacity to exceed 3.6 billion GW, https://www.ecns.cn
12. *Electricity sector in China*, https://www.en.wikipedia.org.
13. *Renewable energy in Australia*, https://google.com.au.
14. Vorini app, *Solar Installations and Growth*, 2024.

15. World coal demand remains at record high as power demand surges, https://www.cnbc.com/2025.
16. Lee Ying Shin, The world is not close to breaking free from coal-in some countries demand is surging, https://www.cbbc.com /2025/02/10.
17. Nick Ferris, What China must do to turn itself off coal, *Energy Monitor*, https://www.energy_monitor.al/section/power, 24 July 2023.
18. Weila Gong et al. The Politics of China's just transition and the shift away from coal, *Science Direct Energy Research and Social Science*. Vol. 115, Sept. 2024. P1-7.
19. *Map of China electricity Grid*. www.geni
20. Nick Ferris. Weekly data. Grid investment in China more than every other country combined, https://www.energy_monitor.al/networks.
21. *Australian spending on high voltage electricity grid*, https://www.google.com.
22. Map, *Australia grid*, https://www.google.com
23. AEMO, *Quarterly Energy Dynamics*, Q4 2024.
24. AEMO, *Inputs, Assumptions and Scenarios Report,* 2023.
25. Giles Parkinson, Consumer attitudes and earlier coal closures: AEMO mulls scenario tweaks of new grid blue print, *Renew Energy*. 28 Feb. 2025.
26. Rachel Millard, Green energy gets switched off as power stations fail to keep up, https:///www.fr.com. 27 Feb. 2025.
27. David Fishman, Lanta Group and interview by Micheal Banard, *Coal and nuclear are very different,* http://Cleantechnica.com. Feb. 2025.
28. Zhao Xuan et al. China changes prices model for world largest power grid, https://asi.nikkei.com.
29. *Wikipedia*, Electricity sales in China, https:wwwen.wikipedia.org.
30. Why China is struggling to wean from coal, https://www.hellenicshippingnews.com Sept 2021, also *The Straits Times*, www.straitstimes.com.
31. Nancy Liu, China indicates coal capacity tariff mechanism from Jan. 1, 2024*, My Steel* liuchuanjan@mysteel.com. 22 Jan. 2024.
32. *Explainer: What are Power Purchase Agreements*, https://www.euruelectric.org/in-detail/ppas/
33. *A CfDs explainer*, https://www.eurelectric.org, 15 March 2024.
34. Marija Maisch, China Scraps energy storage mandate for renewable energy plants, https://www.pv-magazine.com, 17 March 2025.
35. Patrick Durkin, Victorian Government warned about risky funding model to revive wind farm plans, www.afr.com. 4 March 2025, p12.
36. Royce Kurmelovos, Like a Corolla with racing wheels: why Australia's electricity market fails renewables, *Renew Economy*, 9 March 2025.
37. Angela MacDonald-Smith, Green power scheme's flaws after making crucial progress, www.afr.com, 28 Feb. 2025.
38. Giles Parkinson et al., Energy Insiders podcast: Market changes could come quickly, (Nelson Review), *Renew Economy Podcast*, 28 Feb. 2025.
39. Giles Parkinson, Federal and State governments give priority to 56 wind, solar, battery and transmission Projects, *Renew Economy*, March 2025.
40. Anthony Kjar, Power supply outages to cells in aluminium smelters, *Proceedings of the 34th International ICSOBA Conference*, Quebec City, Quebec, Canada, 3-6 Oct. 2016, *Travaux* 45, AL05, 519-528.