A Review of the Problems with Gencost 2018

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1 SUMMARY

1.1 Background

In response to a letter from one of the authors of this paper to his State Member, the Minister for Energy and Environment stated[1] that *'the most economic form of reliable generation is firmed renewables, and this is driving the biggest change in our electricity system's history'*. The Minister's letter also advised the author to seek further information, if required, from a nominated public servant.

The nominated public servant was subsequently contacted and her advice was sought on the reference for the Minister's statement on the economics of renewables. The author was duly advised that the CSIRO publication 'GenCost 2018' was the source.

GenCost 2018 was examined and a number of potential shortfalls were identified. In particular, GenCost 2018 advised that, *" On the other hand LCOE estimates, in their current form, can be misleading if they apply the same discount rate regardless of exposure to climate policy risk and inherently do not recognise the additional balancing technology that is required by variable renewable generation as its share of the generation mix increases. Given the variable renewable share is expected to increase in most Australian states, towards or beyond 50%, this is an issue that needs to be solved."*

Accordingly, a short paper was developed to highlight the shortfalls and clarification was sought from the NSW Government. The Government officials declined to provide further advice and the author was directed to the CSIRO. Correspondence was forwarded to the CSIRO[2] with no response and it was determined that a more comprehensive analysis of the NSW Government's electrical energy policies should be conducted with the view to seeking a meeting with the Minister. This paper is the result of that determination.

1.2 The Carbon Dioxide (CO2) Question

A brief examination of the geological history of the earth confirms that the CO2 concentration in the atmosphere has varied dramatically over millions of years and the earth has not been destroyed.

It may therefore be concluded that the unproven hypothesis that anthropogenic CO2 emissions will result in runaway global warming should not be a serious consideration in the development of NSW energy policies.

Accordingly, any discussion of Carbon Capture and Storage (CCS) and the price of carbon used in life cycle calculations have been eliminated from this paper as they add significant costs to the electricity system with no real benefit.

[1] Minister for Energy and Environment letter MD20/609 dated 7 April 2020
[2] M.Bowden email to CSIRO dated 25 June 2020 and follow-up email dated 15 July 2020

1.3 Methodology

A scenario was developed which included a modern, High Efficiency Low Emissions (HELE) coal fired power station similar to one recently commissioned in Germany. It also featured wind farms based on the Sapphire Wind Farm in NSW. Noting the well-known reliability problems with intermittent wind farms, the wind turbines in the scenario were firmed with either Open Cycle Gas Turbines (OCGT) or Combined Cycle Gas Turbines (CCGT), with technical characteristics that reflect turbines common in the international markets.

The capital and operating costs for each technology were determined using data solicited by the Australian Energy Market Operator (AEMO). Calculations were undertaken to determine the cost per megawatt hour (MWh) of electrical energy and the results compared. The outcomes demonstrated that the cost per MWh generated by the HELE plant was significantly less than the OCGT or CCGT firmed wind farms, which indicates that firmed renewables are not the most economic form of reliable generation.

1.4 Replacing the NSW Coal Fired Power Stations

By 2035, there will be a single remaining coal fired power station in NSW. The NSW Government's Electricity Strategy sets out a plan to deliver three Renewable Energy Zones (REZ) in the State's Central-West Orana, New England and South-West regions. This builds on the NSW Transmission Infrastructure Strategy and supports the implementation of the Australian Energy Market Operator's Integrated System Plan. It is assumed that these REZs are planned to replace the coal fired power stations.

This paper has examined the costs to replace the coal fired power stations with wind farms firmed by OCGTs or CCGTs. These costs are substantial and the questions of who will underwrite these costs and what impact they will have on the retail price of electrical energy remain open.

1.5 The German Experience

Germany has adopted the Energiewende (energy transition) policy of replacing its coal and nuclear power plants with wind, biomass and solar; however, the cost has been enormous and there is now a significant public backlash against the consequent destruction of the environment and the increased cost of electricity.

The combined nameplate rating of Germany's wind and solar infrastructure is approximately double the average demand for electrical energy in that country. Nevertheless, the intermittent nature of the wind and solar farms coupled with their low capacity factors means that their output fails to meet demand with the difference being provided by Germany's conventional generators and energy imported from neighbouring countries. Australia's current planning puts it on a similar path to

Germany; however, Australia does not have the luxury of electrical energy rich neighbours.

1.6 Solar Power

Noting that the Capacity Factor of large scale solar is less than wind and that it therefore requires even greater firming and hence increased costs, it is difficult to justify its inclusion in the electrical energy system. Accordingly, no detailed study of solar has been undertaken in this paper.

1.7 Conclusions

This paper demonstrates that the MWh cost of reliable and dispatchable electrical energy generated by HELE coal fired power stations is significantly less than that generated by firmed renewables and, as such, HELE technology should underpin the NSW Government's energy strategy.

1.8 Recommendations

The NSW Government:

- **Should review the Electricity Strategy and immediately implement a life-extension program for the five extant coal fired power stations.**

- **Should immediately implement construction of additional units at existing coal fired power stations where these were to be provided at a future date. For example, Mt Piper.**

- **Should plan to replace the five coal fired power stations with modern HELE coal fired plants at the completion of their extended lives.**

- **Should ensure all renewable energy (RE) generators must be dispatchable at nameplate rating and be economically viable without subsidies and/or preferential treatment before being connected to the transmission network.**

- **Should ensure transmission infrastructure required by such a connection must be funded by the RE Generator prior to connection.**

2 GEOLOGICAL HISTORY

2.1 Introduction

The NSW Government has promulgated a number of publications that advocate for the increased penetration of wind and solar energy into the electricity system. Underpinning these policies is the unproven hypothesis that fossil fuelled generators emit carbon dioxide which, if left unchecked, will result in runaway temperature increases.

The NSW Government has determined that renewables are now the most economic form of new generation, with a mix of wind and solar firmed with gas, batteries and pumped hydro expected to be the most economic form of reliable electricity.[3] This determination is based on advice promulgated at the CSIRO publication, 'GenCost 2018'.

This paper challenges the GenCost 2018 claim that the cost of renewable energy is less than that produced by fossil fuelled generators and presents a number of scenarios to illustrate the argument.

2.2 The Geological History of the Earth

Figure 1[4]depicts some 600 million years of the earth's temperature record and the concentration of CO2 in its atmosphere.

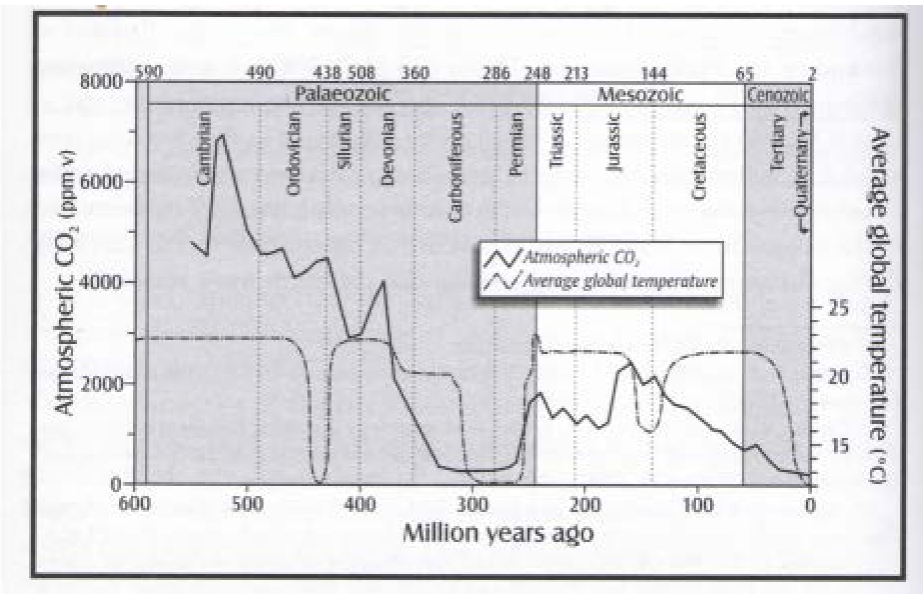

Figure 1 Plot of atmospheric CO2 and Average Global Temperature

[3] NSW Electricity Strategy
[4] https://www.geocraft.com/WVFossils/GlobWarmTest/A6c.html (Sourced from the publications of C.R.Scotese and R.A.Berner)

550 million years ago, the CO2 concentration was about 7000 ppm and the planet did not experience runaway global warming. Today, it is about 410 ppm so a reasonable conclusion is that imminent catastrophic warming due to CO2 is extremely remote. Similarly, the earth's temperature has varied widely over the millions of years and the current trend indicates that the earth is progressively cooling.

For many years, scientists have used ice core analysis to determine the historical temperature of the earth and the CO2 concentration in the atmosphere. The resolution of ice core analysis prior to the 1990's was not detailed enough to determine clearly what came first, the CO2 or the temperature[5]. The expectation was that CO2 came first because in a laboratory situation this "greenhouse effect" can be readily demonstrated. This view became widely accepted and led to the present populist belief that CO2 is the cause of global warming.

More recent evidence at Figure 2[6] confirms that warming **precedes** increasing CO2 rather than the other way around. After temperatures rise, it takes about 800 on average years before CO2 begins to increase.

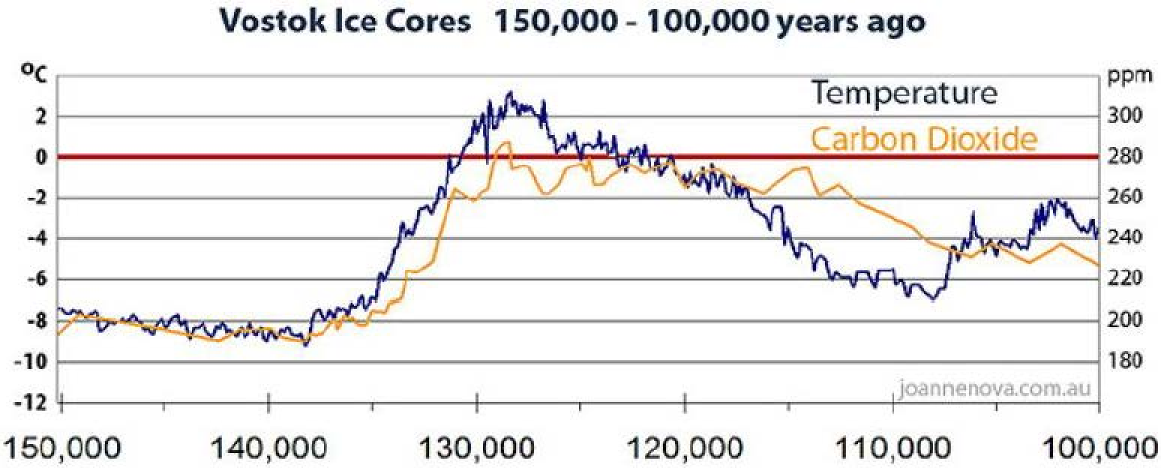

Figure 2 Vostok Ice Core Data

2.3 The Carbon Dioxide Question

Professor Ian Plimer is an Australian geologist, professor emeritus of earth sciences at the University of Melbourne, previously a professor of mining geology at the University of Adelaide, and the director of multiple mineral exploration and mining companies. He recently published the following statement[7]:

[5] https://www.newscientist.com/article/dn11659-climate-myths-ice-cores-show-CO2-increases-lag-behindtemperature-rises-disproving-the-link-to-global-warming/
[6] ibid
[7] Spectator Magazine dated 8 August 2020.

'In the past decade, China has increased its CO2 emissions by 53 %, 12 times Australia's total output of 1.3% of the global total. The grasslands, forests, farms and continental shelves of Australia absorb far more CO2 than we emit. The attack on emissions of the gas of life is an irrational attack on industry, our modern way of life, freedoms and prosperity. It has nothing to do with the environment."

It is also instructive to examine the view of Australia's Chief Scientist, Dr Alan Finkel[8]. On 1 June 2017, Dr Finkel attended a Senate Estimates hearing where Senator Ian Macdonald asked if the world were to reduce its carbon emissions by 1.3 per cent, which is approximately Australia's rate of emissions, what impact would that make on the changing climate of the world? His response was that the impact would be virtually nothing; however, he clarified his statement by explaining that doing nothing is not a position that Australia can responsibly take because emissions reductions is a little bit like voting, in that if everyone took the attitude that their vote does not count and no-one voted, we would not have a democracy. In essence, the Chief Scientist agrees with Professor Plimer that our climate policies are worthless, but suggests that we should at least continue to 'virtue signal' lest we are not considered worthy citizens by other countries!

While the statements of these eminent persons are consistent, it may nevertheless be instructive to validate their views with the following, simple analysis.

2.3.1 Australia's Natural Forests

Australia contains approximately 147 million hectares of Natural Forests (addition to this we have 1.82 million hectares of planting estates and around 440 million hectares of grassland)[9]. With an estimated 4% of the global forest estate, Australia has the world's sixth-largest forest area and the fourth-largest area of forest in nature conservation reserves.

2.3.2 CO2 Absorption Rate

The mechanism for carbon sequestration in trees and plants is photosynthesis, the conversion of atmospheric CO2 into plant material using energy from the sun, releasing oxygen in the process. A single hectare of mature trees absorbs approximately 6.4 tonnes of CO2 per year.[10]

A simple calculation demonstrates that the total CO2 absorption is 147,000,000 * 6.4 which equates to 940,800,000 tonnes of absorbed CO2 by Australia's forests per year.

[8] https://www.chiefscientist.gov.au/2018/12/clarifying-the-chief-scientists-position-on-reducing-carbon-emissions
[9] https://web.archive.org/web/20110604211106/http://www.daff.gov.au/brs/publications/series/forest-profiles
[10] https://www.sfmcanada.org/images/Publications/EN/C02_Sink_EN.pdf

2.3.3 Australia's CO2 Emissions

According to 'Our World in Data', CO2 emissions in Australia in 2017 due to the burning of fossil fuels for energy production and the industrial production of materials such as cement were 417 Mt [11].

2.3.4 Australia's CO2 Balance Sheet

By comparing Australia's annual CO2 absorption with the total Australian emissions, we may conclude that Australia has negative emissions of 523,800,000 tonnes per annum (940,800,000 - 417,000,000) which means that Australia is a CO2 sink**.**

2.3.5 Conclusion.

It is therefore concluded that the unproven hypothesis that anthropogenic CO2 emissions will result in runaway global warming should not be a serious consideration in the development of NSW energy policies. Accordingly, any discussion of Carbon Capture and Storage (CCS) and the price of carbon used in life cycle calculations have been eliminated from this paper as they add significant costs to the electricity system with no real benefit.

[11] https://ourworldindata.org/co2/country/australia?country=~AUS#what-are-the-country-s-annual-co2-emissions

3 WIND AND COAL COST COMPARISON

3.1 Levelised Cost of Electricity (LCOE)

The NSW Government accepts the advice in the CSIRO publication GenCost 2018 (superseded by GenCost 2020) that the cost of renewable energy sources (wind and solar) is less than that of coal fired power stations. However, there are shortcomings in GenCost 2018, particularly in its failure to include the cost of the fossil fuelled generators that are required to 'firm' renewables in its calculations. Surprisingly, the CSIRO is aware of this shortcoming as evidenced by Section 4.1 of GenCost 2018 which states:

‘However, for the much larger community of non-modeller electricity industry stakeholders who want to understand why electricity models give the results that they do, or why investors are making certain technology choices, an LCOE measure, until recently, has been considered a useful guide. **While LCOE has performed this role in the past, it needs to be extended in light of the greater emphasis on variable renewables in the electricity system and their additional balancing costs which are not captured by LCOE calculations.’**

‘While the capital cost projections are primarily designed to be included in Australian electricity modelling studies as scenario inputs we recognise that some stakeholders require access to levelised cost of electricity (LCOE) data for comparing technologies outside of models. On the other hand LCOE estimates, in their current form, can be misleading if they apply the same discount rate regardless of exposure to climate policy risk **and inherently do not recognise the additional balancing technology that is required by variable renewable generation as its share of the generation mix increases. Given the variable renewable share is expected to increase in most Australian states, towards or beyond 50%, this is an issue that needs to be solved.** *This report provides some advice on what comparisons are and are not appropriate using current methods and describes a process by which future updates will seek to solve this issue with new approaches.’*

It is indisputable that, in the absence of wind or sunshine, wind and solar generators cannot provide electricity. Wind and solar plants demonstrate a capacity factor of about 33% and 25% respectively. Wind and solar plants are weather dependent and are therefore unreliable, and if the Australian Energy Market Operator’s (AEMO) reliability target of 99.998% is to be achieved, firming plants in the form of fossil fuelled generators are essential. These must therefore be included in the cost of wind and solar farms if realistic life cycle costs are to be calculated. Note that coal and gas generators do not require firming and are expected to generate electricity 24 hours of each day at their designed Operational Availability target which accounts for down time due to maintenance activities.

Furthermore, the CSIRO admits that it has not accounted for the costs of firming in the LCOE calculations. The following statement from Section 4.5 of GenCost 2018 is pertinent:

*“There are two ways demonstrated here for presenting climate risks (risk premiums and explicit carbon prices), however the solution for making flexible and variable technologies comparable is a much harder technical problem***. As such, we are focussing our attention to the problem of how to extend LCOE by including the additional costs of balancing variable renewables.** *Our goal is to provide an extension to the LCOE calculation which takes into account balancing costs. In broad terms, balancing costs are about how system demand is met from a combination of technologies with a given amount of reliability.”*

Speaking of reliability, GenCost 2018 is silent on AEMO’s system reliability specification of 99.998% which is a fundamental driver of the Operational Availability requirement.

GenCost 2018's Apx Table B.3: Data assumptions for LCOE calculations states that in 2020, the life expectancy for coal fired power stations without Carbon Capture and Storage (CCS) is 25 years. Table 1 provides the year of commissioning data for the NSW coal fired power stations currently operational.[12]

Plant	Commissioning period	Age
Eraring	1982-84	36 years
Bayswater	1982-1984	36 years
Liddell	1971-73	47 years
Mt Piper	1993	27 years
Vales Point B	1978	42 years

Table 1 NSW Coal Fired Power Stations

It is evident that the 25-year life expectancy for coal fired power stations used as an input to the CSIRO’s calculations is significantly lower than observed. Provided the logistic support infrastructure for a new High Efficiency Low Emissions (HELE) Ultra Supercritical (USC) pulverised coal fired plant is maintained, there is no reason that it should not have a life expectancy of 50 years.

Similarly, the Capacity Factor for coal fired power stations is stated as 60% in GenCost 2018. This reflects a future scenario where renewable generators increase their share of demand to the detriment of coal fired generators. Even the ageing NSW coal stations can operate at > 80% of nameplate rated capacity and there is no reason why a HELE plant should not achieve 85% or greater if government policy constraints were removed.

[12] Environment and Communications References Committee ‘Retirement of coal fired power stations’ March 2017.

It is also instructive to note that the latest publication, GenCost 2020, states at Section 1.4 that, *'In 2020, we have prioritised extension of Levelised Costs of Electricity (LCOE) estimates to include the costs of balancing variable renewable energy*. **This research is not included in this report but will be shared with stakeholders during 2020'.** This is regrettable, as published details of the cost of firming variable renewable energy would satisfy the NSW public that its Government is acting on sound advice (provided, of course, that the costs of balanced renewables are indeed less than coal fuelled plants).

In addition, there is no detailed explanation of how the LCOE is determined other than a note at the foot of Apx Table 3b that "*A weighted average cost of capital of 7% was applied unless otherwise noted*". Work by ARENA was included in the references but a review of this work shows that the methodology used does not meet the requirements of project evaluation using Discounted Cash Flow Analysis.

3.2 An Alternative Analysis of the Cost of Electrical Energy

To understand the true cost of firmed wind energy not provided in Gencost 2018, we need to evaluate the cost of firming wind energy with gas as predicated by the Federal and NSW Governments and compare this with the cost of energy from a coal fired power station using, where appropriate, actual costs.

For example, according to Reuters[13], Germany’s new Datteln-4 coal-fired power station began operations on May 30 2020. This plant has a nameplate rating of 1,050 megawatts (MW), cost 1.5 billion Euros and is a High Efficiency Low Emission (HELE) Ultra Super Critical (USC) coal fired plant without Carbon Capture, Use and Storage (CCUS). Pulverised coal is burnt at high temperature with an advanced multistep flue gas purification system, which will eliminate nitrogen oxides, dust and sulphur from the flue gas.

Datteln-4 can be compared with the largest wind farm in NSW, the Sapphire Wind Farm near Inverell. This infrastructure was completed in 2019 at a cost of AUD 590 million and incorporates 75, 3.6 MW wind turbines, thus providing the wind farm with a 270 MW nameplate rating.

Table 2 below summarizes the data.

Generating Plant	**Datteln-4 Germany**	**Sapphire Wind Farm, Inverell, NSW**
Capital Cost	AUD 2.5 billion (1.5 billion euros @AUD 1.66)	AUD 590 Million
Nameplate Rating	1,050 MW	270MW

13 13 https://www.reuters.com/article/us-uniper-coal-datteln/unipers-datteln-coal-plant-set-for-may-30-start-up-idUSKBN2322CP

Generating Plant	Datteln-4 Germany	Sapphire Wind Farm, Inverell, NSW
Energy Source	Coal	Intermittent wind
Technology Employed	HELE USC critical plant without CCS uses pulverised coal with an advanced multi-step flue gas purification system, which will eliminate nitrogen oxides, dust and sulphur from the flue gas.	75 in no 3.6 MW turbines

Table 2 Datteln-4 Coal Fired Power Station, Germany and

Sapphire Wind Farm Capital Costs

In this study, firming will be provided for the Sapphire wind farm with options for an Open Cycle Gas Turbine (OCGT) power plant with a name plate rating of 549 MW and cost of AUD 450.42 million, or a Closed Cycle Gas Turbine (CCGT) power plant with a name plate rating of 519 MW and cost of AUD 609.36 million.

3.2.1 NEM Reliability

The reliability standard of the National Electricity Market (NEM) is defined in clause 3.9.3C of the National Energy Rules (NER) as the maximum expected unserved energy (USE), as a percentage of total energy, in a region over a financial year, and is set at 0.002%.14 USE is measured in gigawatt hours (GWh).

This is a measure of the effectiveness, or sufficiency, of generators in the region to meet demand. AEMO has confirmed that the NEM can operate with 100 per cent renewable energy while meeting the current reliability standard. As weather dependent generation is intermittent, wind energy needs back-up generation ('firming' in AEMO terminology) to meet the required reliability standard.

How do we guarantee 99.998% reliability'? We know that when the wind fails, the wind farms' output may drop to zero. We therefore need to provide back-up for these events which may not be difficult if wind is a very small component of the NEM and we have sufficient dispatchable reserves to cover the outage. But as wind farms penetrate further into the NEM at the expense of dispatchable power plants (gas and coal), the problem increases. Figure 3 illustrates the problem, noting that there is nothing unusual about the wind fluctuations in October 2020.

[14] AEMO has recently revised this to 0.0006% which exacerbates the problem.

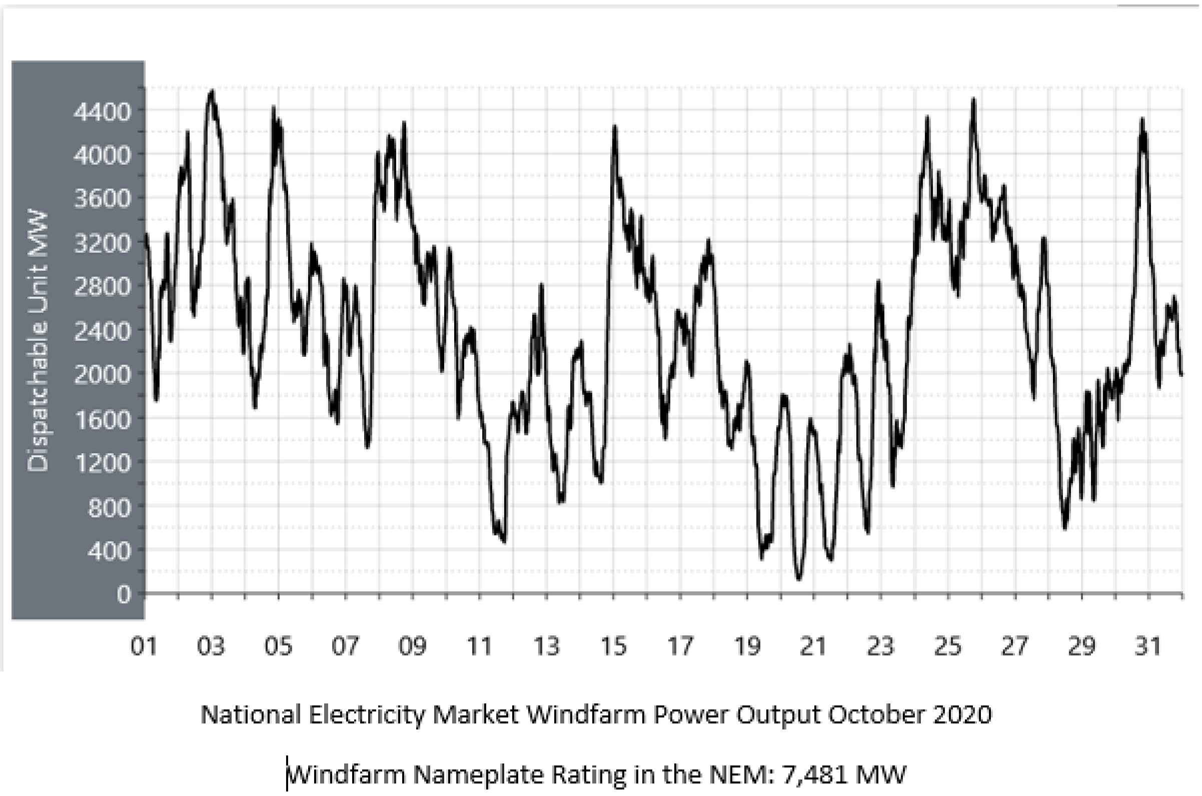

Figure 3 Windfarm power production in the NEM October 2020

Figure 3 clearly demonstrates that the total output of all wind farms in the NEM failed to achieve their nameplate rating and generated insignificant output on numerous occasions.

The problem is also well illustrated at Figure 6 in Section 5, 'The German Experience'. In 2017, Germany had constructed approximately 95 GW of wind and solar power. The country's average demand from 2011 to 2017 was approximately 55 GW. However, despite the availability of almost double the required capacity, the wind and solar generators failed consistently to meet demand. The shortfall was met by conventional generators in Germany and by importing power from neighbouring countries.

3.2.2 Demand Requirements

The Datteln-4 Coal fired plant has a name plate rating of 1050 MW. Four Sapphire Wind Farms, each with a nameplate rating of 270 MW, will be needed to match the rating of Datteln-4.

AEMO requires a system reliability of 99.998% which means that failure to meet demand is intolerable. There are numerous occasions when wind farm outputs tend to zero and the demand must therefore be met by dispatchable generators. Again, this is clearly demonstrated at Figure 4 which illustrates the widely variable output of the 270 MW Sapphire wind farm during October 2020.

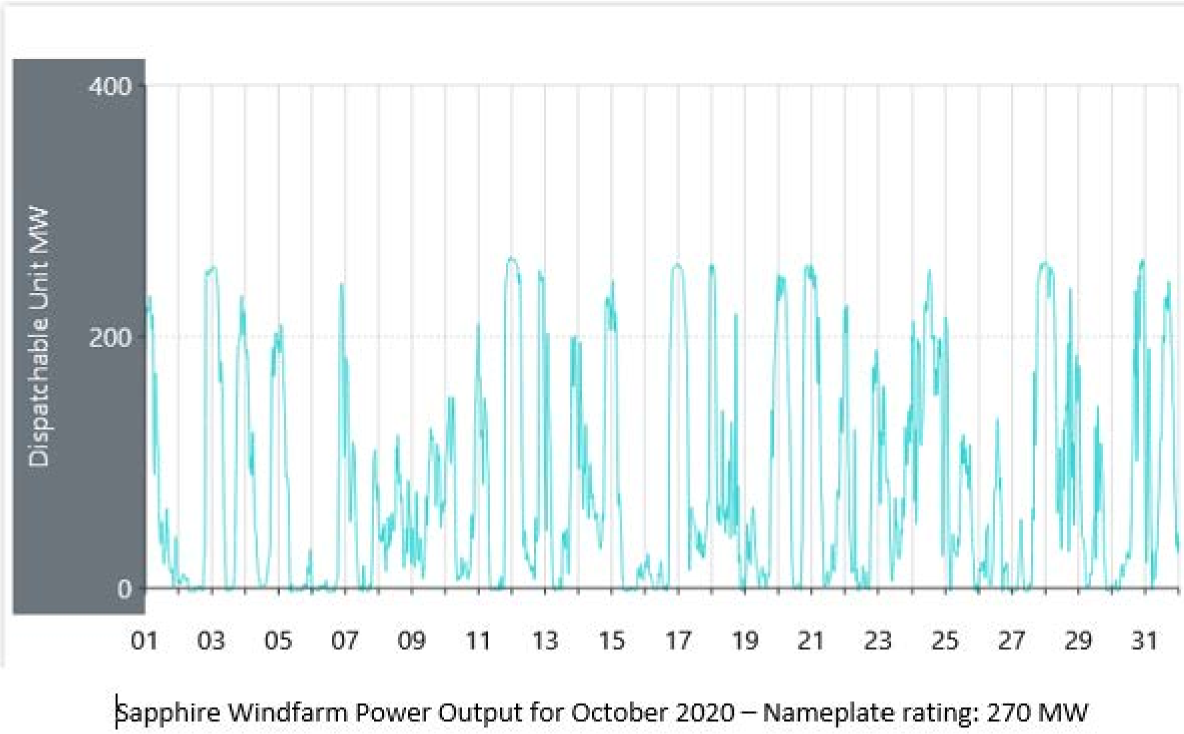

Figure 4 Sapphire Wind Farm Power Production October 2020

It is therefore essential that the NSW electricity system contains at least the same dispatchable capacity as the wind farm nameplate rating. However, what happens when the wind farms' output fails completely as demonstrated at Figure 3?

In essence for every MW of wind nameplate rating, an equivalent MW of OCGT or CCGT nameplate capacity must be constructed and available.

This means two OCGT units rated at 549 MW or two CCGT rated at 519 MW will be required to meet demand requirements.

3.2.3 Lifetime Energy Delivered

A new HELE coal fired power plant should achieve a life expectancy of 50 years with an efficient logistic support infrastructure.

Apx Table B.3: “Data assumptions for LCOE calculations” at GenCost 2018 suggests that wind farms have a life expectancy of 30 years which seems to reflect the more optimistic estimates of the manufacturers. The technical life of wind turbines has been shown to be as low as 12.5 years in overseas studies. For the purposes of this exercise, a life expectancy of 25 years for wind turbines is adopted which appears to match the period of some Operation and Maintenance contracts recently let.

To match the life of the coal plant, it is necessary either to replace or to repower the windfarms at the 25-year point. It is possible to repower wind turbines which involves upgrades to the rotor diameters and new nacelles in order to increase energy production with more advanced turbine technology and to extend the wind farm life. The US National Renewable Energy Laboratory[15] estimates that the 2025 cost to repower a wind turbine is approximately USD1,681 (AUD 2,400 @ 70c) per kW. Therefore, the cost to repower the four Sapphire sized wind farms at the 25-year point may be calculated as follows:

- Cost to repower four wind farms = AUD 2.592 billion (2,700,000 kW * AUD 2,400)

Note also that the gas turbines have a technical life expectancy of 25 years which, over the 50-year timeframe of our evaluation, means that they must be replaced at the 25-year point.

The capital costs are summarized at Table 3

Parameter	Generator			
	Datteln-4	Four Sapphire Windfarms	Two OCGTs	Two CCGTs
Capital cost per plant	AUD 2.5 billion	AUD 2.36 billion	AUD 900.84 million	AUD 1.2187 billion
Name Plate Rating	1,050 MW	1080 MW	1098 MW	1038 MW
Life expectancy	50 years	25 years	25 years	25 years
End of Life replacement		AUD 2.592 billion	AUD 900.84 million	AUD 1,218.72 million
Total capital cost	AUD 2.5 billion	AUD 4.952 billion	AUD 1,801.68 million	AUD 2,437.44 million

Table 3 Capital Cost Summary over 50 Years

3.3 Operation and Maintenance Costs

We have determined that to replace the coal fired power station, we need four by 270 MW wind farms which are firmed by either the two by 519 MW CCGTs or the two by 549 MW OCGTs. This combination meets AEMO’s reliability standards and closely approximates the output of the HELE USC coal fired power station. The estimation of the O&M costs for the OCGTs or the CCGTs over the 50-year period is complicated by the intermittency of the wind farms' outputs.

[15] NREL Report; 'Wind Power Project Repowering: Financial Feasibility, Decision Driver and Supply Chain Effects Table 2'.

The choice of either OCGTs or CCGTs must reflect the requirements of the electrical system. CCGTs are more efficient than OCGTs and hence their life cycle costs are significantly less. However, the ramp up time for OCGTs is significantly faster than CCGTs, hence they are ideal for peaking operations.

When the wind farms fail to meet demand because the wind velocity is too low or too high, then the gas turbines must compensate to meet the load. The fundamental question is how often will the gas turbines be required to ramp up and at what load? The answers lie in the realm of probabilities, presumably underpinned by wind forecasts across NSW which may or may not be accurate. These data are not available to the authors of this paper so a macro approach will be adopted.

To complete the macro cost analysis, the cost of operation and maintenance for the coal fired power station, the wind farms and the firming gas plants must be calculated.

Note also that the cost of transmission lines from the wind farms to the grid has not been estimated as it will vary significantly with geographical locations. It is also instructive to note that 'transmission' is mentioned three times in GenCost 2018 and zero times in GenCost 2020. This is surprising, as the NSW Electricity Strategy defines the electrical system as consisting of four main elements: generation, transmission, distribution and retail.

Error! Reference source not found. details the O&M costing methodology and calculates the MWh cost for each of the four generator types.

Line Item	**Parameter**	**Unit**	**Generating Plant**			
1	Plant name and numbers		Datteln-4 (1)	Sapphire WF (4)	OCGT (2)	CCGT (2)
2	Life of plant - technical	Years	50	25	25	25
3	No of Generating Units	No	1	75	6	6
4	Name Plate Rating	MW	1,050	1,080	1,098	1,038
5	Average Seasonal Net Rating	MW			1,059	994
6	Gross Maximum Energy Production per annum (4)*365*24	MWh	9,198,000	9,460,800	9,618,480	9,092,880
7	Auxiliary Load % of Name Plate Production Output	% of Name Plate	4.00%	3.00%	1.53%	2.50%
8	Auxiliary Load with seasonal losses per annum (4)*(7)*365*24	MWh	367,920	283,824	147,163	227,322
9	Plant Efficiency (Average Heat Rate)	GJ/MWh	9.50	N/A	24.63	10.47

Line Item	Parameter	Unit	Generating Plant			
10	Net Maximum Energy Production = (6)-(8)	MWh	8,830,080	9,176,976	9,471,317	8,865,558
11	Capacity Factor		85.00%	33.00%	47.27%[16]	50.51%
12	Maximum Energy Sent Out per Annum= (10)*(11)	MWh	7,505,568	3,028,402	4,477,092	4,477,993
13	AEMO Marginal Loss Factor		0.9711	0.9553	0.9553	0.9553
14	Maximum Energy Sold = (12)*(13)	MWh	7,288,657	2,893,033	4,276,966	4,277,827
15	Fuel Cost Rate	AUD/GJ	3.50	N/A	5.80	5.80
16	Fuel Costs = (12)*(9)*(15)/1000000	AUD M	250	N/A	639.44	271.80
17	O & M Fixed[17]	AUD/MW	55.86	38.90	4.61	10.90
18	O & M Variable[18]	AUD M	31.60	8.09	47.14	33.00
20	**Total O&M per annum = (16)+(17)+(18)**	**AUD M**	337.46	46.99	691.20	315.70
21	**Total Operating Costs over 50 years**	**AUD B**	**16,873**	2,349.37	34,559.80	15,785.13
22	**Capital Costs of Generation Plant**	**AUD M**	2,500.00	4,720.00	1,801.68	2,437.46
23	**Total Costs (21)+(22)**	**AUD M**	19,350.93	7,069.37	36,361.48	18,222.58
24	**Cost of energy sold =(23)*1000000/C14*50)**	**$/MWh**	**53.10**	**48.87**	**170.03**	**85.20**

Table 4 Cost of Energy Sold by each Generating Plant

3.4 Cost of Windfarm Firming

The cost per MWh for the wind farms firmed by the gas plants may be calculated by totalling the 50-year costs for wind and OCG and wind and CCGT and dividing by the total energy sold in the same time frame. The calculations are detailed at **Error! Reference source not found.**.

Parameter	Windfarms	OCGTs	CCGTs
Total energy sold	144,651,625 MWh	213,848,283 MWh	213,891,352 MWh
Total Cost Total energy sold	$7,069,370,000)	$36,361,480,000	$18,219,080,000

[16] Whilst the Capacity Factors for gas generators is 85%, the Capacity Factors in this scenario have been derated to just compensate for the inability of the windfarms to meet the HELE coal plant's energy production.
[17] Formulae sourced from GHD Report for AEMO Costs and Technical parameters review
[18] Formulae sourced from GHD Report for AEMO Costs and Technical parameters review

Total cost for windfarms and OCGTs or CCGTs combined		$43,430,860,000	25,288,460,000
Total maximum energy sold for windfarms and OCGTs or CCGTs combined		358,499,909 MWh	358,542,978 MWh
Average cost per annum per MWh for windfarms and OCGTs or CCGTs combined		**$121.15 per MWh**	**$70.53**

Table 5 Cost per MWh for Firming Windfarms with either OCGTs or CCGTs

3.5 Summary of Costs per MWh for Generator Types

The costs per MWh for each generator and the firming options are detailed at **Error! Reference source not found.**.

Generator	Cost per MWh
HELE coal fired plant	$53.10
Windfarms unfirmed	$48.87
Windfarms firmed with OCGTs	$121.15
Windfarms firmed with CCGTs	$70.53

Table 6 Summary of Costs of each Generator per MWh

It is evident from the data at **Error! Reference source not found.** that the energy generated by a modern HELE coal fired plant is significantly less expensive than energy produced by firmed windfarms. Whilst the electrical energy generated by unfirmed windfarms is less expensive than coal, unfirmed wind is not an option unless blackouts are accepted as routine.

These data therefore prompt the question of why would governments favour firmed windfarms when their well-documented adverse environmental impacts and significantly greater costs make them uncompetitive with coal in an undistorted market?

When reviewing the evaluation, a question must be asked. "What is the cost of not having a wind farm and not using coal.?' The answer is about $80/MWh for CCGT.

Further the feasibility of using a CCGT plant as firming needs to be reviewed in detail as it is most probable that two CCGT units will not be able to adjust their output to match wind intermittency and one CCGT will most likely be replaced by a OCGT with some curtailment of wind energy expected.

4 THE GERMAN EXPERIENCE

4.1 Overview

The NSW Government might be well advised to examine the outcome of Germany's extensive renewable energy program.

Germany has adopted the Energiewende (energy transition) policy of replacing its coal and nuclear power plants with wind and solar; however, the cost has been enormous and there is now significant public backlash against the consequent destruction of the environment and the increased cost of electricity.

In the past ten years, the price of electricity for households and industry has risen by a third. According to the Augsburger Allgemeine, the price of electricity rose by 35 percent between 2009 and 2019. For a typical household with 4,000 kWh per year, this means 320 euros in additional costs for electricity alone.

As a result, Germany now has Europe’s highest price for electricity, if not the world’s highest price. One kilowatt hour of electricity now costs on average 33 euro cents. Germany is therefore paying heavily for the transition to green energies, as illustrated at Figure 5.

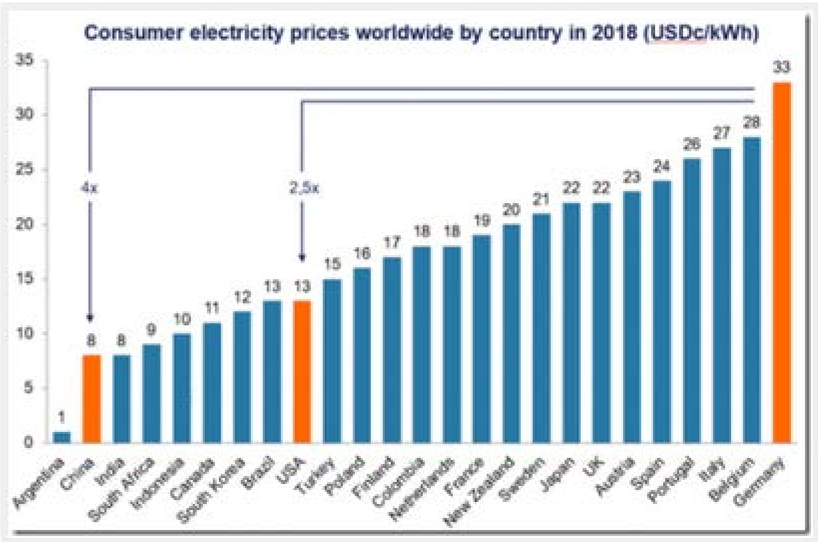

Figure 5 Consumer electricity prices

Figure 6 illustrates the problem for the German electricity generation and distribution system.[19]

[19] Compendium for a Sensible Energy Policy; Vernunfkraft. Bundesinitiative für vernünftige Energiepolitik; November 2017.

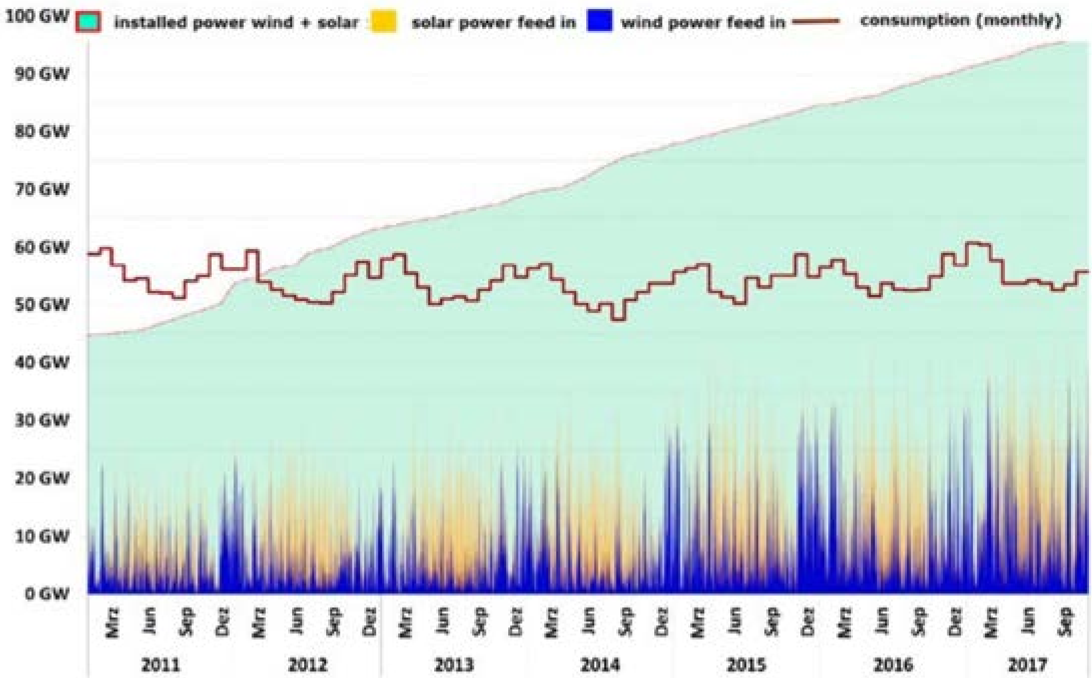

Figure 6 German Electricity Demand versus Renewable Generation

Figure 6 documents the output of German wind turbines and PV systems between 2011 and mid-2017 and illustrates a rapid increase in renewable energy capacity (light blue back-ground). The peak power supplied to the grid by renewables systems (yellow PV, dark blue wind) is also increasing. However, despite the increased nameplate rating and the increasing peaks, the guaranteed output of all 27,000 wind turbines and the 400 million m² of PV systems remains close to zero because of their weather-dependency. This is a particular problem in the winter months, when electricity consumption is high.

Note that although the renewables nameplate rating is around 95 GW, it is unable to meet the average demand of about 55 GW due to the low Capacity Factor. Accordingly, Germany relies on its fossil fuelled plants to make up the difference or imports electricity and gas from neighbouring countries. **Australia is an island and does not have the luxury of relying on its neighbouring countries to import power.**

5 SOLAR FARMS

5.1 AEMO's Statements

The AEMO Renewable Integration Study (RIS) report highlights the challenges with managing increasing uncertainty and interventions with respect to system operability, frequency management and resource adequacy to ensure that a sufficient overall portfolio of energy resources is available to achieve real time balancing of supply and demand. The following extract is instructive:

"...increasingly variable and uncertain supply and demand, and declines in system strength and inertia, have moved the system to its limits, reducing its resiliency and increasing the risk to the system for complex events. The knowledge and tools operators have used in the past to operate the system securely are now less effective and need to be adapted. For example, intervention by AEMO has always been a part of operating a secure NEM, but where it was used rarely in the past as a last resort to manage specific issues on the grid, it has now become commonplace, especially in regions with higher shares of renewable generation (South Australia, Tasmania, and Victoria). This RIS analysis projects that under the current market design the need for interventions to address system security requirements will grow across all NEM regions. Successfully managing the system's increased uncertainty and operational complexity will require different approaches and better co-ordination of all resources. **The existing dispatch process for the NEM was not designed for these new conditions, and the current reliance on operators to balance factors and intervene is sub-optimal and unsustainable***.[20]"*

It is therefore quite clear that AEMO recognizes the unsustainability of the current policy to inject ever increasing renewable power into the electricity system. Noting that the Capacity Factor of large scale solar is less than wind and that it therefore requires even greater firming and hence increasing costs, how can its construction be justified? Even more disturbing is the proliferation of distributed solar photovoltaics (DPV) installed by households and businesses which, according to AEMO:

"Australia has experienced strong growth in DPV generation over the last decade, with parts of the NEM now at world-leading levels. AEMO expects this growth to continue over the next decade. Most DPV systems in the NEM today operate in a passive manner – they are not subject to the same performance requirements as large-scale sources and are not visible or controllable by distribution network service providers (DNSPs) or AEMO, even under emergency conditions.[21]"

In essence, the construction of large scale solar and DPV exacerbates the problem which, according to AEMO, is sub-optimal, unsustainable and uncontrollable. Accordingly, this paper has excluded firmed solar from its analysis.

[20] AEMO 2020, Renewable Integration Study
[21] ibid

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

This paper demonstrates that the MWh cost of reliable and dispatchable electrical energy generated by HELE coal fired power stations is significantly less than that generated by firmed renewables and, as such, HELE technology should underpin the NSW Government's energy strategy.

6.2 Recommendations

The NSW Government:

- **Should review the Electricity Strategy and immediately implement a life-extension program for the five extant coal fired power stations.**

- **Should immediately implement construction of additional units at existing coal fired power stations where these were to be provided at a future date. For example, Mt Piper.**

- **Should plan to replace the five coal fired power stations with modern HELE coal fired plants at the completion of their extended lives.**

- **Should ensure all renewable energy (RE) generators must be dispatchable at nameplate rating and be economically viable without subsidies and/or preferential treatment before being connected to the transmission network.**

- **Should ensure transmission infrastructure required by such a connection must be funded by the RE Generator prior to connection.**

6.3 Authors

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