The energy future of Saudi Arabia is not batteries and photovoltaic solar panels

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Abstract. Recently, North European academics claimed that “Saudi Arabia can accomplish a 100% renewable energy by 2040 that is overwhelmed by PV single-axis following and battery storage”. They moreover say “Battery capacity contributed up to 30% of the full power request in 2040 and the commitment increments to 48% by 2050”. Based on geology, climate conditions, and resources of Saudi Arabia, it is clarified as batteries and photovoltaic solar panels are not the best choice for the country's energy sector. To cover all the energy supply of Saudi Arabia by solar photovoltaic, plus battery capacity to compensate for the solar energy fluctuations, and unpredictability, is not convenient, for both the economy and the environment. Superior results for the environment and the economy may be accomplished by valorising the fossil fuel assets, through the development of high-efficiency plants such as the combined cycle gas turbine plants of Qurayyah, the advancement of innovations for the generation of clean power, counting oxyfuel combustion and carbon capture and storage, and also developing nuclear energy. The development of nuclear power plants may be more advantageous to the economy and the environment than photovoltaic and batteries. Concerning solar energy, parabolic trough solar thermal power plants also along the coast have advantages versus solar photovoltaic, as thermal energy storage could provide dispatchability. Additionally, a centralized power plant works better than many rooftops photovoltaic that will be likely covered by sand, rusted, or cracked after a few years.

1. Introduction

A North European scholar's article [1] titled “The role that battery and water storage play in Saudi Arabia's transition to an integrated 100% renewable energy power system” has claimed that “... Saudi Arabia can accomplish a 100% renewable energy by 2040 by utilizing PV single-axis and battery storage. Single-axis PV contributed 210 GW out of the whole 403 GW by 2040. The commitment expanded to 369 GW out of an add up to 520 GW by 2050. Battery storage contributed up to 30% of the full power request in 2040 and the contribution increases to 48% by 2050.” Apart from using past tense for the coming years, batteries don't produce power. They only store the power delivered by something else to make use of when needed. Moreover, battery storage capacity is still in its infancy, and not demonstrated off the shelf innovation, and it has critical financial, natural, and maintainability that don’t allow their spreading worldwide. Concerning the source of the power that the batteries may store for future discharge, it is difficult to accept that this power can be created by solar photovoltaic (PV) only. They are much less productive and much costlier than what it is depicted. Furthermore, they endure particular issues in Saudi Arabia such as sand that significantly increments the costs and decreases efficiency over time. The lifetime of solar panels in Saudi Arabia is definitively less than the 20 years that are usually assumed in the power purchase agreement of other countries. Contrary to what it may be upheld by articles such as ref. [1] claiming that “Saudi Arabia can accomplish a 100% renewable energy by 2040 overwhelmed by PV single-axis and battery storage”, based on real-world data from the countries that publish cost and electricity production results, we clarify why this suggestion is impracticable and not helpful.
PV solar panels still have critical costs and work with typical capacity factors of around 0.27-0.28 in better situations such as Australia. This is the case of more expensive (per kW of power) energy facilities. The capacity factor can be as low as 0.10 in the event of rooftops [2], [3], [4], [5]. In Saudi Arabia, sand and dust radically diminishes efficiency as well as the lifetime and require costly cleaning frameworks. The capacity factors of individual facilities moreover are affected by variability, with a standard deviation of high-frequency distributions largely above the mean over one year [2], [3], [4]. Indeed, at the grid level, variability is large, as solar energy is never accessible at night time and it also changes during the day and with the season.

Battery storage is in its infancy. The world's biggest battery, installed in Australia, only has 100 MW of nominal power and 140 MWh of nominal energy storage [2]. It is never charged or discharged over 30% of nominal power. Similarly, charging and discharging are not from 0 to 100% state-of-charge but only a fraction of this.

Based on their life cycle appraisals, the use of well-established combined cycle gas turbines plants is better, from financial, natural, ethical, sustainability point of view. In case Saudi Arabia is focusing on a better environment and low carbon energy economy, it would be way better to contribute in nuclear energy for baseload, whereas cultivating more productive utilize of fossil powers through high-efficiency plants such as combined cycle gas turbine plants. Cleaner employments of fossil fuels [6] is additionally an opportunity to investigate.

Concerning solar, parabolic trough solar power created along the coast is more promising than solar PV. Concerning the opportunity to utilize pumped hydro energy storage, Saudi Arabia has no lakes nor rivers. [1] claims, “The role that battery and water storage play in Saudi Arabia's transition to an integrated 100% renewable energy power system”. It must be recalled that Saudi Arabia has no rivers and exceptionally little water. Whereas conventional hydropower in other nations may certainly be modified to pumped hydro by including pumping capabilities [2], Saudi Arabia has no existing hydropower facilities. Coastline pumped hydro is still in its infancy, a single little pilot plant was built, run for few years, and decommissioned in Japan. Not working technologies should not be exaggerated to diminish well-proven technologies.

Here we show the operation of real-world PV and wind within Australia where the high-frequency information about electricity production is made accessible to the public. The Australian national electricity market (NEM) is an open framework where operators and traders purchase and offer electricity with straightforwardness. The Australian NEM information is also discussed in [7].

The information about energy generation from ref. [7] is accessible for every 5 minutes – day by day information – or 3 hours – month to month information, in terms of power or capacity factor. The capacity factor is the proportion of the real producing power to the enlisted capacity. The total enlisted capacity of sun-powered facilities (all PV) is 3,427 MW. The information of ref. [8] is accessible every 30 minutes for the everyday charts and every 3 hours for the month to month charts. The total registered capacity of the sun-powered rooftop is almost 8,000 MW. The information of ref. [9] is accessible every 5 minutes – daily data – or 3 hours – month to month information, as power or capacity factor. The full enlisted capacity of battery energy storage is 191 MW.

2. Results
High-frequency information of solar and wind power generation, climate conditions, and power plant components and system yield is fundamental to plan the energy capacity required to create a stable grid supplied by irregular and unpredictable wind and solar-based energy. To precisely validate and make solid renewable energy software tools, they must be based on high-frequency data (each minute or less) for climate and plant operation.

Fig 1 presents sample results for the Australian National Electricity Market grid, managed by the ANEMO. The capacity factor of wind and solar energy facilities is shown during one sample month and two sample days. The variability is dramatic also at the complete grid level. This requires a huge installed capacity to deliver the energy needed by the grid as well as huge storage to compensate between peaks and valleys.
Figure 1. Australian National Electricity Market grid, managed by the ANEMO. (a) The capacity factor of wind energy facilities during April 2020, Individual facilities and grid average. (b) The capacity factor of solar energy facilities during April 2020, Individual facilities and grid average. (c) The capacity factor of wind energy facilities during 19 April 2020, Individual facilities and grid average. (d) The capacity factor of solar energy facilities during 19 April 2020, Individual facilities and grid average. As some facilities are registered before being fully completed, their nameplate capacity may change over the year, and the registered capacity is updated with a delay, some capacity factors may exceed 100. Sunday 19 April before 6 AM very little renewable energy was supplied by wind and solar. (e) The capacity factor of wind energy facilities during 20 April 2020, Individual
facilities and grid average. (f) The capacity factor of solar energy facilities during 20 April 2020, Individual facilities and grid average. The night after, wind energy facilities were operating at a 70% capacity factor rather than the less than 3% capacity factor of the day before. Images reproduced modified from [10].

3. Conclusions
The only two countries on earth providing transparent data of renewable energy are the United States and Australia. The United States Energy Information Administration (EIA) publishes the actual electricity production of every plant in the country, renewable or not renewable, every month, since 2001, or the registration of the plant if later. The Australian Energy Market Operator (AEMO) publish the actual electricity production data of every plant in every state of the country excluded Northern Territory and Western Australia.

The low-frequency data show a capacity factor of about 30-33% of large PV or CSP solar, as well as wind energy facilities, and significant seasonal variability. The high-frequency data show a much more dramatic variability not only at the single plant level but also at the full grid level. During nights of low wind, no matter larger may be the installed capacity, the electricity production is proven to be negligible. This call for a proper reassessment of the capacity of solar and wind needed, based on the actual power of generating power across the year, as well as the power and the energy of the massive storage needed to make a power grid overwhelming wind and solar balanced.

In terms of average performances over a year, the 250 MW CSP parabolic trough of Solana, with limited dispatchability thanks to 6 hours of thermal energy storage, has a capacity factor of 36% at the cost was 2 billion $. Without thermal energy storage, and no dispatchability 250 MW CSP parabolic trough of Genesis has a capacity factor of 28% at the cost of 1.25 billion $. The first plant is expected to work for 20-25 years, the second up to 30 years (examples of similar SEGS plants built in the 1980s). The Crescent Dunes solar tower with thermal energy storage of cost 1 billion $ for 110 MW has been already shut down after only 4 years for lack of production (it has produced in the 4 years less than what was expected in every single year).

Costs are better with PV, but with life not expected to last more than 20 years (and very likely they last much less) and zero dispatchability. Solar Star had for 597 MW a cost of 2.5 billion $ for a capacity factor of 32.5%. The less performing desert Sunlight had for 563 MW a reported cost, likely underrated of 1.46 billion $ for a capacity factor of 26% and the same technology Topaz for 585.9 MW had a cost of 2.50 billion $.

Regarding wind, of life only 20 years, the Roscoe Wind energy facility of power 781.5 MW had a cost above 1 billion $ for a capacity factor of 32%. The units I to IX of Alta Wind, totaling 1,320 MW, had a cost of 2.875 billion $ for a capacity factor of 25%. The 496.6 MW Bison Wind Energy Center had a cost of 0.8 billion $ for a 33% capacity factor. There is no reason to expect better performances for wind and solar plants in Saudi Arabia than in the United States or Australia, due to the extreme temperatures plus sand and dust that are particularly challenging.

The Qurayyah IPP gas and oil-fired combined cycle power station in Qurayyah, Saudi Arabia had a cost of 2.85 billion $ for 3,927 MW. The plant was properly designed to cope with sand and dust and extreme temperatures. Experience from the United States tells us that the natural gas combined-cycle power plants operated in the 50% to 80% capacity factors range in 2015. Considering the fuel conversion efficiency is 52%, and the electricity production is completely controllable rather than fully unreliable as per wind or solar, the cost of oil and natural gas, and the availability of oil and natural gas, there is no doubt that the present and near future of Saudi Arabia must be gas and oil-fired combined cycle power stations. Regarding the life span of these plants, the Rabigh-2, a two 413-MW, combined-cycle blocks using oil, of 826 MW of total power was completed in 1988 and 1993, and it is well working in 2020 after 32 and 27 years respectively, without being cracked or rusted.

The real cost of dispatchable electricity by solar PV plus batteries based on real-world experiences is summarized below, by using the cases of Solar Star and Topaz for what concerns the solar energy by PV without storage, and the latest Hornsdale expansion for what concerns the battery storage. Solar PV in Saudi Arabia is expected to produce less energy and have a shorter lifetime than in California. Similarly, batteries in Saudi Arabia are expected to have reduced efficiency and lifetime when compared
to batteries in South Australia. The cost of the battery storage of the Hornsdale expansion is 0.77 million $US per MWh (71 million AUS equivalents to 49 million US$ for 64 MWh).

Solar star 1 and 2 have a nominal power of 579 MW and a capacity factor of 0.325. This means the actual power is 188 MW. The cost was 2.5 b$. Neglecting O&M cost and assuming 30 years’ lifespan, the cost of electricity is about 0.05 $/kWh (=2.5e9/188e3/30/365/24). The minimum battery requirement is 188x12 MWh actual or 188x12x2 MWh nominal. If we take the life span 30 years and we do not consider O&M costs, the additional storage cost is about 3.75 b$ (=0.77x188x12x2/1000). This is optimistic. If we take the life span 15 years and similarly we do not consider O&M costs, the additional storage cost is about 7.0 b$. The total cost inclusive of storage is thus about 0.19 $/kWh. About the same numbers are given by Topaz. Topaz has a nominal power of 589.5 MW and a capacity factor of 0.25. Thus, the actual power is 147 MW. The cost was 2.5 b$.

Neglecting O&M cost and assuming 30 years’ lifespan, the electricity cost is about 0.065 $/kWh (=2.5e9/147e3/30/365/24). The minimum battery storage needed is 147x12 MWh actual, 147x12x2 MWh nominal.

By assuming a life span of 30 years and no O&M costs, the additional cost is about 2.7 b$ (=0.77x147x12x2/1000). By assuming a more realistic life span of 15 years and no O&M costs, the additional cost is about 5.4 b$. The total cost inclusive of storage is thus about 0.20 $/kWh.

As solar energy has a strong correlation, this is roughly the cost that high-efficiency solar PV plant technologies would have to power for example NEOM City. The current state of renewable energy is well represented by ref. [11], and it is very far from what is portrayed. Opposite to the present or the near future, in a future not that close there is certainly the need for a mix of solar, wind, and novel nuclear power plants, with all of them requiring significant investment in research and development, to reduce the share of oil and natural gas. Especially wind and solar must be made better, producing more and costing much less, for both the economy and the environment. More specifically, the future of Saudi Arabia by 2040 can’t be PV solar panels and batteries. Their economic and environmental costs will be unaffordable, as with present technologies they will damage even more the environment versus the present situation wasting huge amounts of money.

4. References
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