THE ROAD TO RENEWABLE: 100% RENEWABLE ELECTRICITY IN NEW ZEALAND WITH WIND, SOLAR AND SEASONAL ENERGY STORAGE

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Overview

This paper imposes a 100% renewable generation constraint on the New Zealand electricity market to determine the least-cost configuration of wind, solar and seasonal energy storage that enables the country to reach a true 100\% renewable goal while resolving dry year exposure. A representation of the future New Zealand electricity market is formed using scaled historical demand and historic hydro generation patterns. New large scale wind and solar electricity outputs are derived from atmospheric weather models to incorporate the variability caused by weather-dependent energy generation. Feasible combinations of wind, solar and seasonal energy storage are determined over an 18-year study period under the constraint that no demand interruption or blackouts occur.

The results indicate that New Zealand can cost-effectively reach its 100% renewable generation goal by 2030 without increasing electricity prices through the construction of a proposed large scale pumped hydro storage – Lake Onslow. The optimum size is found to be 3.90 TWh of seasonal energy storage, growing to 5.7 TWh to satisfy 2050 demand. An unfortunate trade-off between wind and solar was revealed, induced by their different generation profiles in the New Zealand climate.

Wind is more cost-effective as it better matched the winter demand peak, required a smaller storage capacity and resulted in less drawdown of the energy storage. However, the lower cost comes at the risk of energy security as wind was found to be less predictable between years compared to solar. Energy spill was cost-optimal in all scenarios even when combined with battery storage, suggesting spill is expensive to avoid. This report concludes that seasonal energy storage is cost-effective in reaching the 100% renewable goal and decreasing dry year exposure, but the trade-off between wind, solar and seasonal storage capacity will require careful consideration due to the complex relationships and risks between the wind-solar-storage trade offs.

Methods

New Zealand faces existing and worsening challenges in ensuring energy security due to the dominance of hydro-generation (about 65% of total generation) and low energy storage capacity. Most hydro-infows occur in the spring/summer wet-season when demand is lowest, but New Zealand has limited ability to store this excess energy for the winter peak in demand with only 38 days of electricity storage. Electricity demand is expected to double by 2050, as the transport and industrial sectors are electrified. To achieve 100% renewable electricity will mean building out of large scale wind and or solar power.

Academics and industry stakeholders dispute how best to solve dry year risk with a dramatic increase in intermittent renewables. Current solutions either involve retaining thermal peaking (perhaps power to gas), overbuilding renewable generation or constructing long-term storage, such as a seasonal pumped hydro energy storage scheme or green hydrogen production and storage.

The aim of this work is to evaluate the proposal for a large scale pumped hydro storage in the South Island – Lake Onslow. The proposed storage lake would increase hydro storage in NZ by a factor of at least three and would be the largest such facility in the Southern hemisphere. This analysis imposes a 100% renewable electricity constraint to determine the least-cost optimal configuration of wind, solar and seasonal pumped hydro storage that would enable New Zealand to reach its goal while safeguarding against the dry-year risks posed by hydro dominated generation.

Hydro generation is assumed to follow historical dispatch with geothermal output scaled to take into account anticipated build. Historic demand from 2000 to 2018 is linearly upscaled to 2030, 2035, 2050 projected electricity demand levels to preserve historical demand patterns. Remaining demand is assumed to be met by Wind and Solar output which is simulated using Nasa's MERA 2 data to hindcast output for historical meteorological years over an 18 year period from 2000-2018 for various combinations of solar and wind installed capacity.

The model simulates representative electricity markets in 2030, 2035, and 2050 across thousands of configurations of wind, solar and seasonal battery to find the least-cost optimal configuration that enables the country to reach 100\% renewable electricity and resolve dry-year risks.

Projected demand, the expected generation mix (hydro, geothermal, existing wind, wood) and combinations of new wind and solar capacities are simulated to construct a daily imbalance (supply minus demand) over the 18-year period. Intra-day imbalances are assumed to be balanced via hydro smoothing or grid-scale lithium-ion batteries.

The daily imbalance charges or discharges the seasonal storage over the 19-year period to determine if the storage at its modelled capacity, efficiency and initial charge can fully service the market. The constraints on the seasonal storage are that it must never fully discharge over the 18-year period (as that would imply power system blackout due to non-supply) and cannot exceed its maximum capacity. Above the maximum capacity, excess energy is spilled.

The costs for the feasible configurations of wind, solar and seasonal battery are determined based on their respective LCOEs and storage capacity cost. The trade-off considered is between higher or lower wind and solar capacity compared to the cost of larger storage capacity while still meeting the constraint that blackouts are avoided The costs for the feasible configurations of wind, solar and seasonal battery are determined based on their respective LCOEs and storage capacity. The trade-off considered is between higher or lower wind and solar capacity compared to the cost of larger storage capacity while still meeting the constraint that blackouts are avoided.he least. The simulation searches for least cost combination.

Results

We find that large capacities of wind generation provide the least-cost solutions to meeting the 100\% renewable electricity goal while solving dry-year risks. Most years and scenarios utilise a small amount of solar, implying there is a small seasonal cost synergy between the two generation types.

To meet 2030 demand, a combination of 2000 MW of new wind, 50 MW of solar and 3.9 TWh of seasonal energy storage provides the least-cost solution under the base scenario. Ultimately to meet 2050 demand, the combined generation capacity must increase 8,950 MW, while seasonal energy storage capacity needs to increase to 5.7 TWh. Wind is favoured over solar due to its lower levalised cost and seasonal generation pattern.

These results assume no output costraints on Lake Onslow discharge (generation). Whilst there is some uncertainty in the output capacity of Lake Onslow in practise there will be a constraint on Lake Onslow output. Using a plausible capacity for the dam we repeat the exercise and find that a more balanced combinations of Solar and Wind is favoured with no combination achieving the goal of no generation shortfall. Thus in these simulations we had to impose a penalty of (VOLL) if there was a shortfall. Optimal storage capacity is similar to the no capacity constraint scenario.

Conclusions

We find that a 100% renewable electricity system is feasible with large amounts of intermittent generation. Surprisingly the system costs are dominated by new build of renewable generation compared to the costs of the pumped storage system. Although the impetus for the proposed Lake Onslow pumped hydro storage scheme is to manage dry risk we find in our modelling that its main function is to manage daily imbalances of intermittenent generation. Indeed some years that were considered as 'dry years' historically see an increase in renewable output over the year with the result that Lake Onslow sees a net increase in hydro storage over the year.

Turning now to simulations with a capacity constraint on Lake Onslow our simulations finds some days with generation shortfalls. Indeed these are remarkably persistent, even if renewable generation is ramped up considerably. In further work we will examine if hydro redispatch or power to gas thermal can resolve these problems.