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Impact of climate change on solar and wind electricity generation in Aotearoa New Zealand

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Abstract

Climate change is driving the energy sector with significant impacts on renewable electricity generation systems. The purpose of this study is to analyse the impact of climate change on solar and wind electricity generation in Aotearoa New Zealand projected to 2050. To have realistic and tangible results and reduce the uncertainties, climate change is modelled with three climate and economic scenarios. The annual electricity generation projected for 2050 is estimated through simulations conducted with SAM (System Advisor Model), using data provided by NIWA. The projected energy output in 2050 is compared with the electricity production of two solar farms and five wind farms in 2024. The results show that solar electricity generation will be similar to the data that the Electricity Authority captured for 2024, with some slight seasonal variations. Wind-generated electricity is likely to be more affected by climate change, with a substantial increase in average wind speed in winter and spring, especially on the southern island. A decrease in wind in summer and autumn reduces wind-generated electricity. The risks to the reliability and stability of solar and wind power generation systems are particularly amplified by the increase in extreme weather events, such as intensified storms, atmospheric rivers, and floods. This study highlights the vulnerability of Aotearoa New Zealand's energy sector to climate change, and the need for adaptation strategies. The recommendations include flexibility of power grid management with alternative sustainable electricity generation solutions and storage strategies and strengthening solar and wind farm infrastructure to make them more resilient and durable against extreme weather events.

Keywords: Climate change; Solar electricity generation; Wind electricity generation; Climate scenario modelling; Energy system resilience.

1. Introduction

Climate change will significantly alter natural resources and renewable energy production, bringing both challenges and opportunities. Changes in temperature, precipitation and wind patterns will affect all current renewable energy systems, but especially solar, wind and hydropower. Aotearoa New Zealand generates over 80% of its electricity from renewable, with a target of 100% by 203O. According to NIWA's Statement of Intent for 2023/2024, "*the Government is committed that by 2035, half of our energy consumption (40% in 2021) will come from renewable sources, and that New Zealand will have 100% renewable electricity by 2030 (82% in 2021)*".

However, geographical location and topography of Aotearoa New Zealand make it highly sensitive to climate change, requiring a reassessment of energy strategies in terms of sustainability and efficiency. Its renewable energy portfolio – mainly hydroelectric, with increasing wind and solar power – faces risks linked to climate change. Wolfe (2025) warns that dwindling hydro and gas reserves could threaten energy security, particularly in dry winters. Research by Purdue (2024) indicates that models based on historical climate data are no longer adequate, as climate change is already altering wind speeds and water availability.

By 2050, electricity demand is set to double due to the electrification of transport and industry (BCG, 2022), with wind power providing almost a third of the mix and solar power expanding. However, these systems remain climate-dependent. Understanding the effects of climate change is therefore essential to ensure the reliability, stability, and sustainability of renewable energy systems.

1.1. Rational of the research

The impact of climate change on renewable electricity generation systems has been researched at a national scale. Purdie (2024) reveals that climate change could alter wind patterns and water flows, challenging wind, and tidal power generation systems, two key energy resources in Aotearoa New Zealand. However, it is necessary to understand the impacts of climate change on a regional scale with the best possible adaptation of infrastructures so that they remain sustainable. Depending on the geographical location, the topography of the site, and the types of generation systems, the impacts of climate change are different and so are the adaptation solutions. Depending on these different criteria, proper factors must be considered to obtain tangible results. This study is motivated by the need to understand the impact of climate change on renewable energy generation systems, including solar and wind in Aotearoa New Zealand, a country that now depends on more than 80% of these sustainable systems for its daily electricity consumption.

1.2. Research objectives

This study aims to assess the impact of climate change on solar and wind electricity generation in Aotearoa New Zealand, with a focus on identifying vulnerabilities and developing adaptation strategies to support the country's renewable energy and decarbonisation goals. Current planning relies largely on historical climate data, overlooking future changes in wind regimes, solar irradiance, and rainfall patterns, as well as the increasing frequency of extreme weather events. This creates a significant risk to energy security and system stability. Research (Purdie, 2024) indicates that altered wind speeds and drier summers—especially on the North Island—could reduce the performance of solar and wind systems. Additionally, shrinking hydro and gas reserves further threaten supply reliability.

To address these challenges the study aimed to:

- quantify projected impacts of solar irradiance and wind speed on energy generation capacity by 2050;
- model future climate scenarios (RCPs and SSPs) using regional case studies;
- identify seasonal and regional vulnerabilities in generation systems;
- assess the geographic sensitivity of infrastructure to extreme weather events; and
- provide adaptation recommendations for energy planners.

The overarching goal is to support the design of resilient renewable systems that can withstand the evolving climate conditions of the coming decades.

2. Literature review

This section establishes the theoretical and empirical foundation of the study by critically examining existing global and regional research on the effects of climate variability on renewable energy infrastructure. It focuses on how key climatic variables—such as wind regimes, solar irradiance, temperature fluctuations, and the frequency and intensity of extreme weather events—affect renewable electricity production. The review identifies the current methodologies used in climate-energy modelling, highlights gaps in regional analysis, and assesses adaptation strategies proposed in the literature. By grounding this study within a broader academic and practical context, the review helps justify the need for a region-specific approach tailored to Aotearoa New Zealand's unique geographical and meteorological profile.

2.1. Global context and scenario-based modelling

Many studies emphasise the importance of integrating climate change projections into renewable energy system planning. Peter (2019) compared two investment scenarios: one that anticipates climate change, and one that does not. The results showed that failure to consider climate change leads to increased reliance on fossil fuels and higher system costs. Conversely, planning with climate projections in mind supports a more cost-effective and sustainable energy mix, including increased offshore wind deployment. Bonjean et al. (2016) extended this idea to a continental scale, assessing how wind and solar potentials vary seasonally across Europe. Their results demonstrate pronounced spatial variability: wind generation increases in parts of Germany and the Baltic, while solar output shows an east-west divide. These scenario-based studies rely heavily on climate models such as the Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs). Schlott et al. (2018) applied RCP8.5 to model cost-optimal energy networks in Europe, finding shifts in optimal energy mixes as capacity factors change. They used mathematical formulations, such as capacity factors and Pearson correlation coefficients, to convert climate inputs into power system data. Similarly, Perera et al. (2019) emphasized the value of using multiple climate scenarios to assess the robustness of multi-energy systems under future climate variability, focusing on trade-offs between net present value and grid integration.

2.2. Impacts on solar electricity generation

Solar PV systems are particularly sensitive to changes in irradiance, temperature, and atmospheric conditions. Solaun and Cerdá (2019) noted that aerosols and dust reduce irradiance and, consequently, PV efficiency. Pérez et al. (2019) found seasonal differences in solar output in the Canary Islands, with winter gains due to reduced cloud cover and summer losses due to reduced efficiency because of PV deterioration caused by rising temperatures. Their study used models incorporating irradiance, air temperature, and wind speed, validated with high-resolution regional climate projections.

Oka et al. (2020) contributed a robust methodology using data from global climate models downscaled to 1 km resolution. Their research simulated PV performance under various RCPs, showing increased potential in winter and reduced performance in summer due to overheating. Importantly, they also modeled technological improvements in PV efficiency, illustrating that innovation can mitigate climate-induced losses. They stressed the importance of designing PV infrastructure to withstand strong winds and heat stress, especially in storm-prone regions.

2.3. Impacts on wind electricity generation

Wind energy, due to its cubic relationship with wind speed, is highly susceptible to even small climate-induced changes. Russo et al. (2022) proved how declining air density due to global warming reduces wind power density (WPD). They used models incorporating equations like the logarithmic and power-law profiles to project hub-height wind speeds. These projections are critical for identifying future high-potential wind sites and improving turbine design.

Rosende et al. (2019) applied a Mixed-Integer Linear Program (MILP) over an 85-year horizon to compare wind energy scenarios with and without climate change considerations in Chile. Their findings showed increased wind investment under RCP8.5, particularly in offshore sites. Schlott et al. (2018) found comparable results, noting stable wind capacity in Northern Europe but declines elsewhere. These changes need spatially differentiated investment strategies.

In Aotearoa New Zealand, Purdie (2024) found that wind regimes are projected to shift significantly by 2050. Southern regions may experience a 4.2% wind speed increase, while the North Island could see declines up to 2.8%. These changes imply both risks and opportunities for electricity generation. Higher wind speeds can improve capacity factors but may also push turbines beyond cut-off thresholds, resulting in shutdowns.

2.4. Extreme weather and infrastructure vulnerability

Extreme weather is increasingly recognised as a major threat to renewable energy infrastructure. Panteli and Mancarella (2015) documented how storms, floods, and heatwaves disrupt power systems, cause physical damage, and lead to prolonged outages. Using Markov models and Monte Carlo simulations, they illustrated the spatial variability of these risks. Fragility curves and failure rate models helped quantify infrastructure susceptibility to specific weather conditions. These insights are particularly relevant for Aotearoa New Zealand, a geographically isolated island nation prone to atmospheric rivers, cyclones, and high winds. Goddard et al. (2025) projected an 88% to 116% increase in the most extreme atmospheric river events on the South Island. These could flood solar installations, damage inverters, and overwhelm wind turbines. The literature emphasises the need for infrastructure hardening, including underground cabling, elevated PV mounts, and stronger turbine foundations.

2.5. Modelling techniques and computational challenges

The reviewed literature shows a growing reliance on high-resolution climate and energy system models. However, incorporating long-term, high-frequency data remains computationally demanding. Hilbers et al. (2019) addressed this by introducing "importance subsampling," which identifies critical time steps for system behavior under peak loads or minimum generation periods. This technique enhances model accuracy without overwhelming computational resources. Advanced software tools like SAM are used to simulate performance under different scenarios. These tools integrate climate variables with technical specifications to estimate energy output, efficiency, and capacity factors. They are critical for validating projections and testing sensitivity across a range of assumptions.

2.6. Adaptation strategies and policy implications

Multiple studies suggest that technological innovation and spatial diversification are vital adaptation strategies. For wind energy, offshore expansion and the development of floating turbines are promising, especially where wind speeds are expected to rise. For solar PV, the focus is on heat-resistant materials, improved cooling systems, and reinforced structural designs.

Policy recommendations include incorporating climate projections into national energy planning frameworks, revising building codes for renewable infrastructure, and investing in grid flexibility. Perera et al. (2019) showed how incorporating multiple climate scenarios into energy hub optimization leads to more resilient designs, though at increased capital costs.

These strategies align with the needs of Aotearoa New Zealand, where renewable systems already provide over 80% of electricity and the government targets 100% by 2030. As extreme weather becomes more frequent and regional variations intensify, localised, data-driven approaches are essential. Energy planners must also consider equity issues, ensuring that rural and vulnerable communities support reliable access during disruptions.

2.7. Research gaps and relevance to Aotearoa New Zealand

While international studies offer valuable methodologies and insights, their findings are not directly transferable to Aotearoa New Zealand due to its unique geography, topography, and climate. The literature reveals a lack of regional studies that combine climate projections with operational data from local renewable systems. This gap is especially problematic given the country's reliance on variable renewables and the increasing incidence of extreme weather. Furthermore, limited research exists in the synergistic effects of multiple climate stressors, such as simultaneous temperature rises and wind speed drops, or how infrastructure degradation interacts with operational efficiency. Most models also assume static technology, underestimating future innovation.

3. Research methods

The study adopted a causal research design to investigate how projected climate change scenarios will affect solar and wind electricity generation in Aotearoa New Zealand by 2050. The method involved the collection of historical and projected climate and energy data, simulation modelling, and comparative scenario analysis focused on five wind and two solar farms on both islands, as summarised in Figure 1.

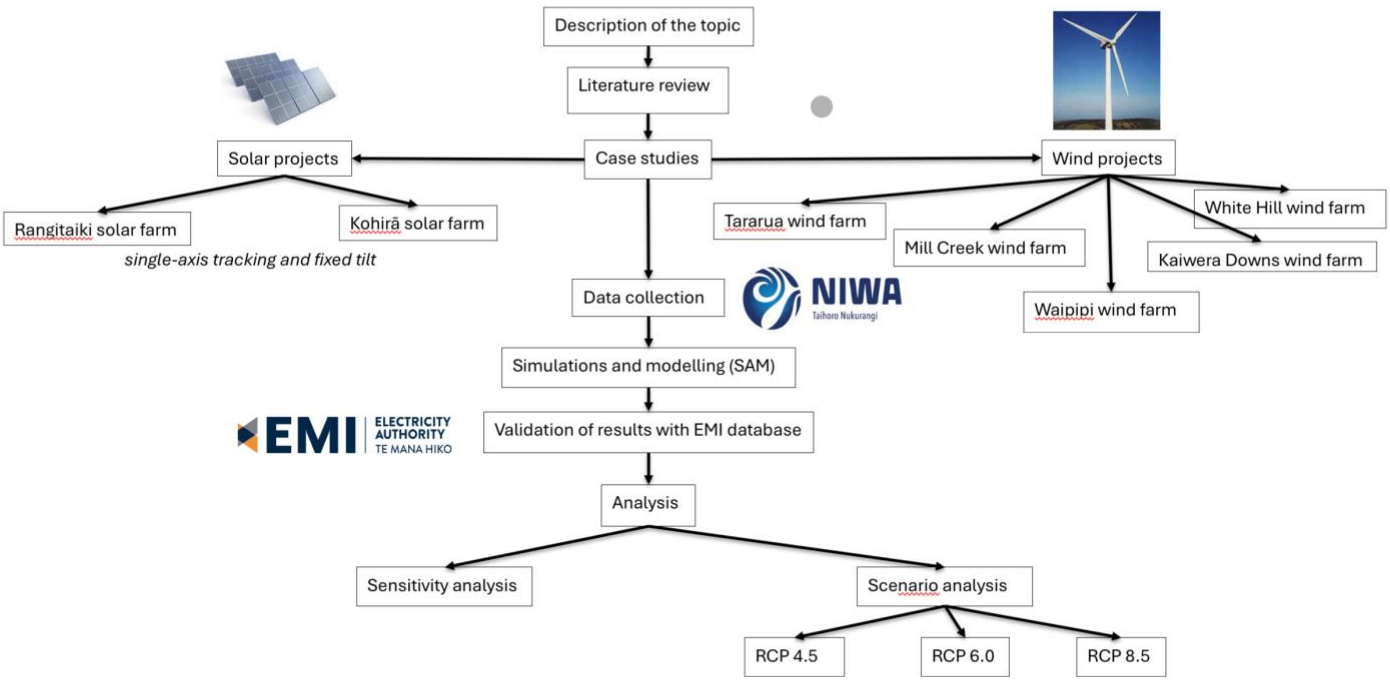

Figure 1. Research approach

3.1. Case studies selection and data collection

Seven representative renewable energy sites were selected:

- Solar farms: Kohirā (Northland) and Ranhgitaiki (Bay of Plenty).
- Wind farms: Tararua, Mill Creek, Waipipi, Kaiwera Downs, and White Hills.

These case studies cover diverse geographic and climatic conditions in Aotearoa New Zealand to guarantee region-specific insights.

Solar and wind historical data for year 2024 were sourced from the Electricity Authority's Electricity Market Information (EMI) database (2024 half-hourly generation data). Climate projections were collected from the NIWA (National Institute of Water and Atmospheric Research) database with a focus on temperature, irradiance (DNI and DHI), wind speed at turbine hub height, and air density.

3.2. Simulation and modelling

The System Advisor Model (SAM) software was used to simulate both solar and wind electricity outputs under different climate conditions. For solar simulations, Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI), and temperature data were modelled to estimate energy output and panel efficiency. For wind energy, the Wind Power Density (WPD) was calculated using:

$$\mathrm{WPD} = \frac{1}{2} \cdot \rho_{\mathrm{air}} \cdot v_{\mathrm{wind}}^3$$

where ρ is air density and v is wind speed.

The simulated outputs were validated against historical generation data using correlation analysis.

3.3. Evaluations

The key parameters evaluated were solar irradiance (W/m^2), energy output (kWh), and temperature-dependent panel efficiency for solar simulations, and wind speed, WPD, turbine efficiency, and energy output (kWh) for wind simulations. Performance metrics were computed on an hour basis for seasonal and annual assessment.

3.4. Sensitivity and scenario analysis

Sensitivity testing involved varying key parameters (e.g., ±10–20%) to identify the most impactful variables under uncertainty. Climate scenarios were modelled using Representative Concentration Pathways (RCPs) and Shared Socioeconomic Pathways (SSPs):

- SSP1 – 2.6 (low emissions).
- SSP2 – 4.5 (moderate).
- SSP3 – 7.0 (high emissions).

Combined RCP-SSP scenarios allowed realistic forecasting of climatic, economic, and policy-driven impacts on renewable electricity generation systems.

4. Results and discussion

This section presents the modelled impacts of projected climate change on solar and wind electricity generation in Aotearoa New Zealand by the year 2050. Simulations were conducted using the System Advisor Model (SAM), integrating historical performance data and regional climate projections obtained from the National Institute of Water and

Atmospheric Research (NIWA). The analysis evaluated changes in key electricity generation parameters under three integrated climate scenarios – SSP1-2.6 (low emissions), SSP2-4.5 (moderate emissions), and SSP3-7.0 (high-emissions) – which reflect a range of plausible socio-economic and radiative forcing pathways.

The results are presented separately for the solar and wind energy systems, focusing on both seasonal variability and regional differentiation across a set of representative solar and wind farms. Each subsection highlights expected changes in resource availability (e.g., solar irradiance, average wind speed), generation output, and system performance metrics under each scenario, offering insight into potential vulnerabilities and adaptation needs within Aotearoa New Zealand's future renewable electricity landscape.

4.1. Solar electricity generation

4.1.1. Seasonal and scenario-based changes in solar irradiance

Two representative solar farms (Kohirā and Rangitaiki) were studied under each combined RCP-SSP scenario. Overall, changes in solar irradiance were minimal but exhibited seasonal variability (see Table 1):

- Spring saw most notable increases, especially under SSP3-7.0, with irradiance gains of +4.4 W/m^2 at Rangitaiki and +3.1 W/m^2 at Kohirā.
- Summer results diverged: Kohirā experienced declines across all scenarios, while Rangitaiki showed slight increases except under SSP3-7.0, which let to a -1.4 W/m^2 reduction.
- Autumn and winter both showed minor positive trends, with increases of up to +1.2 W/m^2.

Table 1. Seasonal solar irradiance changes for Rangitaki and Kohirā under SSP1-2.6, SSP2-4.5, SSP3-7.0

Change in average solar radiation (W/m^2)		Rangitaiki	Kohira
Spring	SSP1-2.6	+3.7	+2.4
	SSP2-4.5	+3.0	+2.7
	SSP3-7.0	+4.4	+3.1
Summer	SSP1-2.6	+0.5	-2.3
	SSP2-4.5	+0.6	-1.5
	SSP3-7.0	-1.4	-2.7
Autumn	SSP1-2.6	+1.2	+1.2
	SSP2-4.5	-0.3	-0.3
	SSP3-7.0	+0.5	+0.9
Winter	SSP1-2.6	+0.9	+0.1
	SSP2-4.5	+1.2	+1.2
	SSP3-7.0	+0.8	+0.9

4.1.2. Projected Plane of Array Irradiance (POAI) and solar output

The Plane of Array Irradiance remained stable across all scenarios for both solar farms (see Appendices A and B in the Supplementary Material):

- Rangitaiki exhibited a notable summer increase of +50 W/m^2 under SSP1-2.6, which translated to moderate generation gains.
- For both farms, seasonal shifts in POAI resulted in slight annual increases in electricity generation across scenarios.

- Kohirā saw decline in summer output, consistent with its observed irradiance drop, but remained stable during other seasons.

4.1.3. Implications for solar electricity generation

Despite seasonal variations, the projected changes in solar electricity generation are insignificant at the annual scale. The analysis suggests that solar infrastructure in Aotearoa New Zealand remains resilient under all future climate scenarios evaluated. The results imply that no immediate adaptation of existing solar systems is necessary, though ongoing monitoring is called for.

4.2. Wind electricity generation

4.2.1. Seasonal and scenario-based changes in wind speed

Wind speed projections revealed strong seasonal and regional variability across the five analysed wind farms (see Table 2):

- Spring presented the largest increases, particularly under SPP3-7.0:
  - Kaiwera: +5.4%.
  - White Hill: +5.0%.
- Summer showed modest declines, especially for:
  - Waipipi: -2.1% (SSP2-4.5).
  - Kaiwera : -2.2% (SSP3-7.0).
- Autumn experienced the most significant reductions under the scenarios SSP3-7.0, including:
  - Tararua: -3.0%.
  - Mill Creek: -3.3%.
  - Waipipi: -3.5%.
- Winter saw slight increases in wind speed, particularly for farms in the South Island.

Table 2. Annual wind electricity output per farm across climate scenarios – 2024 vs. 2050 projections

NZ Onshore	2024	2050		
New Zealand		SSP1-2.6	SSP2-4.5	SSP3-7.0
Wind AC Elec generation	MWh	MWh	MWh	MWh
Tararua	109 179	108 533	108 892	108 285
Mill Creek	229 141	230 485	237 318	222 161
Waipipi	439 818	429 986	429 790	424 705
Kaiwera	147 961	151 250	152 603	152 823
White Hill	160 576	166 412	169 838	169 443

4.2.2. Wind electricity generation projections

Changes in wind speed translated to distinct patterns in annual energy output (see Appendix C in the Supplementary Material):

- North Island wind farms showed losses in electricity generation, particularly under SSP3-7.0:
  - Waipipi: -3.56%, equivalent to a loss of 15,113 MWh/year.
  - Mill Creek: dropped from +8,177 MWh (SSP2-4.5) to -6,980 MWh (SSP3-7.0).

- South Island wind farms – notably Kaiwera and White Hill – showed increased generation under all scenarios, aligning with the spring wind speed boost.

4.2.3. Implications for wind electricity generation

The findings reveal that climate change poses a greater risk to wind electricity generation than to solar particularly in the North Island. Seasonal declines, especially during autumn, could lead to supply shortages without adequate adaptation planning. In contrast, South Island wind farms may benefit from increased spring wind speeds potentially offsetting regional deficits.

These results highlight the need for:

- Grid flexibility to balance seasonal generation peaks and troughs;
- Storage solutions or load shifting to mitigate production inconsistencies; and
- Region-specific adaptation strategies, such as turbines upgrades or diversified site selection.

4.3. System resilience and emerging risks

While this modelling accounted for seasonal irradiance and wind variability, it did not include extreme weather events, which are becoming more frequent in Aotearoa New Zealand. According to NIWA projections, AR5 (Atmospheric River Category 5) events could double in frequency, particularly in the South Island's west coast. These events pose risks of flooding, infrastructure damage, and prolonged downtimes, especially for wind farms with turbines reaching cut-out speeds or ground-mounted solar systems vulnerable to debris and water damage. Increased cloud cover and storm-induced panel degradation are additional concerns for solar farms. Therefore, while the annual electricity generation outlook is still relatively stable – particularly for solar – system resilience may be undermined by turbine shutoffs during extreme winds, damage to inverters and transformers from flooding, and prolonged outages from physical infrastructure failure. This highlights the necessity of future-proofing renewable systems through robust engineering standards, advanced forecasting tools, and the integration of storage and flexible grid technologies.

4.4. Discussion

The results of this study provide valuable insight into how climate change is expected to affect solar and wind electricity generation in Aotearoa New Zealand by 2050. It has been shown that annual electricity generation remains stable overall for solar energy. This is not the case for wind power generation, which shows more substantial regional variations and significant seasonal vulnerabilities. The aim of this section is to discuss the results and their implications in comparison with existing literature, highlighting the challenges for system planning, infrastructure adaptation and policy-making.

The projected stability of solar energy generation across all scenarios aligns with findings from Pérez et al. (2019) and Oka et al. (2020), who observed minimal long-term losses in solar PV output despite rising temperatures. In this study, increases in spring irradiance largely offset minor declines during summer, resulting in only marginal changes to annual solar output at the Kohirā and Rangitaiki farms. These results suggests that solar power infrastructure in Aotearoa New Zealand is less sensitive to projected climate variabilities than wind power generation systems at least under the current SSP-RCP trajectories. However, the systemic risks associated with extreme weather conditions must be considered as well. The increasing frequency and intensity of atmospheric river events, particularly on the west coast of the South Island (Goddard et al., 2025), poses growing threats to ground-mounted photovoltaic infrastructures, and could destabilise the apparent resilience of these systems. These risks include:

- Flooding and sedimentation, which can degrade or destroy inverters and electrical housing;
- Wind borne debris during storms, risking physical damage; and
- Persistent cloud cover, which reduces generation during extreme weather events.

The risk of intermittent but important losses during extreme weather events, even if not considered by annual averages, needs to be seriously considered in solar system design and site choice to ensure a reliable and stable supply of electricity.

Unlike solar, wind power output shows greater susceptibility to climate-induced seasonal and geographic shifts, particularly under high-emissions scenarios. This vulnerability is pronounced in North Island wind farms, where summer and autumn wind speeds are projected to decline, leading to measurable eductions in output. The results for the Waipipi and Mill Creek wind farms prove that these systems could face production losses exceeding 3% annually, with autumn becoming the most constrained season. This is consistent with findings by Purdue (2024), who projected seasonal wind regime shifts in northern New Zealand. Given that wind energy currently plays pivotal role in balancing hydro variability during dry seasons, these findings signal a potential threat to seasonal grid reliability. Conversely, South Island wind farms – especially Kaiwera and White Hill – are projected to experience increased output, especially in spring and winter, under all modelled scenarios. This divergence highlights the need for regionally nuanced energy planning and more robust inter-island transmission capacity to smooth out seasonal mismatches. Moreover, the threat of extreme wind events (such as those triggered by intensified AR systems) cannot be overlooked. Turbines may increasingly hit cut-out speeds, halting generation to protect mechanical systems. Prolonged or frequent shutoffs could worsen the mismatch between supply and demand, especially during peak demand events in winter storms.

4.4.1. Limitations of this study

The limitations are linked to the uncertainty of long-term meteorological data, and to the impossibility of accurately determining the behaviour of solar and wind power generation systems to the variability of extreme weather events. The results clearly demonstrate that overall national production figures mask significant temporal and spatial variations, which could have considerable effects on grid stability. For instance, high seasonal variability in wind generation could require expanded energy storage capacity, particularly for autumn shortfalls. Grid flexibility, including smart demand response and real-time load balancing, will become increasingly essential, and diversification of renewable sources, such as further deployment of geothermal or offshore wind, may provide critical resilience, to meet peak winter demand. Furthermore, the correlation between emissions trajectories and generation loss (especially for wind) reinforces the importance of global mitigation. Under SSP3-7.0, not only do emissions soar, but the operational reliability of renewable generation infrastructure begins to erode in certain regions.

These findings reflect broader international patterns. For example:

- Schlott et al. (2018) found similar divergence in capacity factors for onshore vs. offshore wind in Europe under RCP8.5.

- Studies in Chile (Rosende et al., 2019) and Japan (Oka et al., 2020) confirm that solar irradiance remains relatively stable under climate change, while wind shows high geographic sensitivity.
- Russo et al. (2022) emphasised that even minor reductions in wind speed can drastically reduce power generation due to the cubic relationship between wind speed and energy output.

It is therefore essential for region-specific studies to be able to work with precision on solutions adapted to each renewable electricity production system. The results obtained argue in favour of region-specific infrastructure planning, flexible national energy strategies and policy frameworks based on future scenarios to complement the results gathered with historical data.

5. Conclusion and recommendations

5.1. Main outcomes

The study set out to assess the projected impacts of climate change on solar and wind electricity generation in Aotearoa New Zealand by 2050. The research aimed to quantify the influence of climate-driven changes in irradiance and wind speed, evaluate spatial and seasonal vulnerabilities, and provide actionable insights to inform future adaptation strategies. Using regional climate projections from NIWA and performance modelling through SAM, the study quantified how changes in solar irradiance and wind speed will affect electricity generation. The results demonstrate that solar generation is expected to remain stable, while wind generation is significantly more sensitive to seasonal and regional climate shifts (particularly under the high emissions scenario SSP3-7.0)

By focusing on a diverse set of solar and wind farms across both islands, the study identified clear regional differences in climate vulnerabilities. Wind farms in the North Island (especially Waipipi and Mill creek) are projected to experience notable generation declines in summer and autumn, while South Island sites such as Kaiwera and White Hill may benefit from increases spring wind speeds. Seasonal variation is thus confirmed as a critical factor in future energy planning.
The study confirmed that wind speed variability (due to its cubic relationship with wind power output) is the most influential factor for wind energy systems. For solar systems, temperature and irradiance changes had minimal impact, indicating a more climate-resilient performance profile.

Although average annual generation appears stable, the rising frequency and intensity of extreme weather events (e.g., atmospheric rivers, storms) presents a significant threat to the operational reliability of both wind and solar infrastructure. This points to a growing need for system-level resilience measures such as storage, structural reinforcements, and real-time monitoring.

5.2. Recommendations

The results of this study show the importance of considering different climate scenarios in energy planning. That is why national and regional energy strategies should incorporate scenario-based climate modelling, using SSP-RCP frameworks to stress-test infrastructure plans and guide investments. Given the regional variability in wind generation, particularly the vulnerability on North Island wind farms and the increased potential in the South Island, future development should be geographically targeted and informed by site-specific projections.

Grid resilience must be enhanced through greater flexibility and electricity storage capacity to manage seasonal variability and potential generation deficits, more specifically during peak demand periods. Investments in technologies such as battery systems, pumped hydro, and real-time load management will be essential to maintain supply stability. Infrastructure standards for both solar and wind systems should be revises to address growing risks from extreme weather events, including flooding, strong wind, and thermal stress.

Further research is needed to model the direct impact of extreme events (such as atmospheric rivers) on renewable infrastructure performance and downtime. Future work should also explore economic, social, and equity considerations tied to adaptation strategies, ensuring that energy transition remains not only technically feasible but also socially and financially sustainable.

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