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A 21st Century Climate in New Zealand

New Zealand (NZ), a developed country with a unique landscape, diverse topography, and a variety of ecosystems is facing the challenges of Anthropogenic Climate Change (ACC). Situated in the South Pacific Ocean near the 41st parallel south and the 174th meridian east, NZ is comprised of two main landmasses and hundreds of smaller islands. The diverse landscape is home to around 5.1 million people, over 15,000 km's of coastline spanning 268,838 square kilometers ($km^2$). Over 75% of the population resides within 10 km of the coast on the volcanically active northern island (CIA 2023). The Northern Island has a temperate maritime climate, lush rolling hills, and volcanic plateaus, making it ideal for agriculture and harnessing geothermal energy. (CIA 2020; IEA 2021). The Southern Island with its rugged Southern Alps has a cooler, wetter climate, playing a crucial role for hydroelectric energy production (CIA 2020; IEA 2021). While renewable energy makes up over 80% of the grid, their carbon dioxide equivalents ($CO_2$-e) per capita is the 6th highest of Annex I countries (GHGIS 2020). NZ, with a Gross Domestic Product (GDP) of $219.8 billion, sees the agriculture sector contributing 5.7% to the economy, yet it was responsible for nearly half of the nation's total $CO_2$-e (CIA 2021; GHGIS 2022). The impacts of ACC, especially in the coastal regions of NZ, present challenges such as rising temperatures, shifting precipitation patterns, and sea level rise. However, the government is addressing these impacts with measures like the Climate Change Response (Zero Carbon) Amendment Act 2019, the NZ Greenhouse Gas Inventory, and various other methods and policies, demonstrating a commitment to reducing their contribution of greenhouse gas (GHG) emissions (NZGZC 2019; NZG 2021).

Over the last 31 years, New Zealand has measured emissions and kept a Greenhouse Gas Inventory. From 1990 to 2021, gross GHG emissions increased by 18.7%, from 64,720.1 kilotonnes (kt) to 76,824.6 kt $CO_2$-e. Through machine learning, NZ uses the Dynamic Nowcast approach to project yearly estimates of GHG's, with a latency of less than 2 months, this method allows a systems check to verify the GHG inventory the government keeps (NZGHGI 2023; Jones et al 2023). While GHG contribution is low on the global scale, the per capita emissions equated to 16.9 t $CO_2$-e (GHGIS 2022). The primary contributors to this rise include increased enteric fermentation (cow burps) from dairy cows, growth in transportation industries, increased use of synthetic nitrogen in agricultural fertilizers, and rising fuel consumption in manufacturing and construction industries. During the same period, net GHG emissions increased 25.1% (NZGHGI 2023). In 2021, NZ's GHG emissions were primarily from carbon dioxide ($CO_2$) at 45%, methane ($CH_4$) at 43%, nitrous oxide ($N_2O$) at 10%, and fluorinated gases at 2%.

The two sectors emitting most were agriculture (49.2%) and energy (41%), accounting for over 90% of NZ's total $CO_2$-e. The Land Use, Land-Use Change, and Forestry (LULUCF) sector mitigated 27% of those emissions, which reduced the net emissions down to 55,746 kt $CO_2$-e in 2021 (NZGHGI 2023). While LULUCF plays a significant role in mitigating GHG's, it's presented with a unique set of challenges when it comes to accurately measuring the carbon captured (Jones et al 2023). NZ has a more calculated approach to measuring GHG emissions in its energy sector, adopted from the Common Reporting Format (CRF) and the guidelines of the Intergovernmental Panel on Climate Change (IPCC). Utilizing the IPCC references for verifying $CO_2$ from fossil fuel combustion, emissions are measured with a higher level of certainty, while the figures for non-$CO_2$ GHG's are more variable and less certain (Jones et al 2023; NZGHGI 2023). By inventorying and checking datasets through machine learning, NZ can accurately analyze each sector.

The Energy sector in New Zealand includes the emissions produced during all energy generation and the release of fuel related emissions during production and transmission (fugitive emissions). In 2021 a significant portion of New Zealand's electricity came from hydropower (55.5%), geothermal energy (18.4%), and wind power (6.0%) (NZGHGI 2023). Fossil fuel based thermal plants that combust coal, oil, and gas contributed 17.8% to the country's electricity supply. During the year, the Energy sector contributed 31,210.1 kt $CO_2$-e, which accounted for 40.6% of New Zealand's GHG emissions. The Dynamic Nowcast method showed that Energy emissions in 2021 were 32,388 kt CO2-e, reflecting a relatively high confidence in governments accuracy (NZGHGI 2023; Jones et al 2023). The main contributors within the energy sector were road transportation (40.5%), manufacturing industries, and construction activities (20.2%). Between 1990 and 2021 emissions in this sector increased by 30.7% primarily driven by growth in the transportation and construction industries (NZGHGI 2023). While the Energy sector contributed a significant amount of GHG's, the Agriculture sector had the highest emissions, presenting unique challenges.

In 2021, the agriculture sector accounted for 49.2% of New Zealand's gross GHG emissions, amounting to 37,786.1 kt $CO_2$-e. This was primarily because of enteric fermentation (cow burps)

(73.7%), agricultural soils (cultivation & fertilizers) (19.4%), and manure management (4.4%). Since 1990 A large portion of emissions were driven by a 644% increase in the use of synthetic nitrogen fertilizer, an extremely energy-intensive process is required during production of these synthetics. This was due to the expansion in dairy farming, with market demands and government incentives influencing the increase (NZGHGI 2023; Kaine et al 2023). Farmers in New Zealand are now raising more dairy cows and fewer beef cattle and sheep, mainly because dairy farming is becoming more profitable and there's a shift into sustainable agriculture (Kaine et al 2023). Although the sector's emissions peaked in 2014, there was a slight decrease of 1.5% from 2020 to 2021. This was mainly because there were fewer dairy cows and sheep, and farmers were using less synthetic nitrogen fertilizer. This trend shows how sensitive New Zealand's agriculture industry, which relies a lot on pastures and grazing, is to climate change. It also highlights the country's effort to use better methods for keeping track of emissions (NZME 2023; GHGSI 2022).

From 1990 to 2021, New Zealand's Industrial Processes and Product Use (IPPU) sector had a 28.8% increase, accounting for 5.9% of total GHG's. This was primarily driven by the expanded use of hydrofluorocarbons (HFCs) in refrigeration and air conditioning systems. The LULUCF sector reported net emissions at -21,078.2 kt $CO_2$-e in 2021, reflecting a 4.5% decrease since 1990. This decrease is largely attributed to slow forest growth and the emissions associated with sustainable harvesting of the forests (NZGHGI 2023). Lastly, the Waste sector accounted for 4.2% of the country's gross GHG emissions, an 18.5% decrease from 1990 levels (NZGHGI 2023). This decline is because of improvements in waste management and landfill gas (LFG) recovery. However, the efficiency of LFG capture systems varies widely across landfills in NZ, providing a focus area for recovering and converting the methane into useable energy (UA 2021). Although there has been an increase of emissions in all sectors since 1990, the methods of monitoring and mitigating have increased in accuracy and efficiency, encouraging NZ to make ambitious updates to their original Paris Agreement Pledges (GHGIS 2022; NZG 2021).

New Zealand's 2021 Nationally Determined Contribution (NDC) projects ambitious strategies and commitments through 2030 under the Paris Agreement. NZ has pledged to reduce its net GHG emissions to 50% below the gross levels of 2005 (88,082 kt $CO_2$-e) (NZG 2021; Crippa et al 2023). This ambitious target is planned through a multi-year emissions budget, calculated to be 571,000 kt $CO_2$-e. Considering the gross emissions in 2021 were over 75,000 kt $CO_2$-e, meeting this goal will require new initiatives, policies, and laws (NZG 2021; GHGIS 2022). In its journey towards achieving this NDC target, New Zealand is placing a strong emphasis on domestic emissions reductions across all sectors. NZ is focusing on enhancing Negative Emissions Technologies (NET's), mostly through forestry. However, with the expansion of dairy farming, economic incentives for afforestation are not nearly as profitable for landowners (Kaine et al 2023). The agriculture and energy sectors are at the forefront of the NDC, aggressive afforestation and achieving a 100% renewable electric grid is the goal for 2035. Considering renewable electricity is estimated between 80 to 85% of the current grid mix, this alone will not meet the emissions reduction goal. While NZ has net zero GHG's by 2050 written into law, the current policies are insufficient to achieve that goal (CAT2023). NZ is already experiencing and will continue to face challenges if new policies are not implemented, and their goals are not achieved.

New Zealand has identified a range of physical and socioeconomic impacts due to ACC. The average annual temperature has risen 1.1°C, 2022 was the warmest year on record. This warming trend is geographically uneven due to the topography and likely to influence the frequencies and intensities of precipitation patterns (NIWA n.d.; IPCC 2021). Southern and western areas are increasingly wetter, while northern regions are experiencing drier conditions more frequently. These trends pose significant health risks, especially to vulnerable populations such as the elderly and agricultural workers (CEFA 2023; NIWA n.d.). Indigenous tribes, such as the Māori communities, many of whom reside near coastal areas, face threats from sea level rise (SLR) and coastal erosion (NIWA n.d.). Sea levels have risen 20 cm over the last century and are projected to increase 23 to 28 cm by 2050 (IPCC 2021; CEFA 2023). However, NZ is in a tectonically active region, vertical land motion is a geological variable that must be considered. Depending on rising or sinking landmasses, accurate assessments of SLR impact become more critical (Denys et al 2020). In terms of ecological effects, climate change is altering species' ranges and habitats. For example, dengue fever and malaria cases are on the rise due to mosquitos thriving and expanding their normal habitats. Coastal and marine ecosystems are faced with challenges like ocean acidification, habitat squeeze, and shifts in ocean productivity. The commercial fishing industry is already seeing declines in annual yields and projections show a further 29% decrease based on a 2-3°C increase in temperatures (NIWA n.d.; Parsons et al 2020). Freshwater ecosystems are projected to have warmer temperatures, changes in water cycles, and a rise in algal blooms. The inland ecosystems are expected to experience disruptions in seasonal patterns and heightened susceptibility to invasive species (IPCC 2021; NIWA n.d.). The diversity of impacts will be exacerbated by increased storms, especially in the coastal regions.

Increased temperatures have a strong positive correlation with increased frequency and intensity of extreme weather events (IPCC 2021). Natural disaster response and infrastructure repair costs turn physical implications into economic impacts. In February 2023, Cyclone Gabrielle brought record levels of precipitation, killed 11 people, and caused over $8 billion worth of damages to NZ (Tandon 2023). The vulnerability created by storms like Gabrielle are projected to increase along with temperatures. The IPCC's Assessment Report 6 (AR6) highlights a significant increase in the frequency and intensity of the most destructive cyclones. The AR6 provides 5 scenarios called Shared Socioeconomic Pathways (SSP) that provide impact projections based on the trajectory of GHG emissions. SSP1-1.9 is considered sustainable energy with low GHG emissions, while SSP5-8.5 is considered continued fossil fuel developments, or business as usual (IPCC 2021). Projections suggest by 2040, under SSP1-1.9, average temperatures in New Zealand could be 0.7°C to 1.0°C higher than they were between 1986 and 2005, increasing the change in precipitation patterns (IPCC 2021; CEFA 2023). Shifting precipitation patterns projected in the 21st century could lead to an 18% increase for hydroelectric power during the winter. Adversely, over a 20% decrease could be seen in summer and autumn, highlighting how increased annual discharge does not positively correlate to increased hydroelectric (Jobst et al 2022). The excess water being spilled during high flow events cannot be harnessed for power generation. Currently there is $12.6 billion worth of infrastructure at risk from storm surges and flooding (CEFA 2023). Under the second lowest scenario, SSP1-2.6, SLR is projected to increase by 30 cm which would expose another $6 billion worth of buildings (IPCC 2021; CEFA 2023). Approximately 10,000 homes in New Zealand are projected to lose insurance coverage by 2050 because of the hazards associated with coastal flooding (CEFA 2023). Changing climate patterns not only increase the likelihood of floods and the unpredictability and severity of extreme weather events, but also contribute to the domestic and global economic impacts.

The economic projections due to climate change in New Zealand are impactful. Data suggests a trend where increased frequencies of droughts could lead to a reduction in the GDP by approximately 0.5%. At the same time, increased precipitation patterns resulting in storms and floods are projected to further diminish the GDP by nearly 0.7% (CEFA 2023). The costs associated with a changing climate extend to a range of sectors affecting both national and global economics. Domestic and international trade, migration, and agricultural productivity are all linked to the changing climate (CEFA 2023). As global temperatures increase, substantial challenges for New Zealand's economy will be faced. New Zealand's ambitious NDC’s carry their own economic issues, projections indicate that achieving these goals will result in 2050’s GDP being 1.2% lower than what it would be under a business-as-usual scenario (CEFA 2023). The projected decrease in New Zealand's GDP by 2050 suggests a possible slowing down in economic growth. Reducing GHG’s and creating policies to incentivize and enforce them is expensive. It's important to understand that these issues are not straightforward and to meet Paris Agreement targets, NZ will have to implement more stringent policies (CEFA 2023; CAT 2023). These projections highlight the different aspects of potential economic impacts that need to be considered.

Considering the agriculture sector is largest emitter of GHG's in NZ, The Ministry for the Environment did an in-depth analysis on sheep and beef farms. In 2018, the pastures for these animals acted as a carbon sink, removing 5,487 kt $CO_2$-e from the atmosphere. However, emissions were driven by deforestation for both expansion of pastures and timber harvesting (NZME 2021). NZ analyzed 10.4 million hectares of farmland, using the Land Use and Carbon Analysis System (LUCAS) to categorize different vegetation. The LUCAS analyzed how much carbon was stored or released in natural forests. They used data from forests that existed before 1990 to determine the number of emissions they contributed. Planted forests absorbed $CO_2$ as they grew but released it during harvesting and decay. Deforestation and clearing grasslands added more $CO_2$ emissions, contributing 14% of New Zealand's GHG's (NZME 2021). Projections suggest that planted forests on these farmlands will become a net source of emissions, averaging 2000 kt $CO_2$-e annually from 2024 to 2030 (NZME 2021). Emissions data indicates that pre-1990 natural forests contributed significantly to $CO_2$ removals. However, the harvesting of planted forests, particularly those established in the 1990s, is expected to increase net emissions in the future. The study revealed that New Zealand is focusing research on land use and ways of capturing carbon. The LULUCF sector reduced gross emissions by 21,078 kt $CO_2$-e in 2021, however the cows and sheep grazing some of these lands contributed 27,859 kt $CO_2$-e from enteric fermentation (cow burps) alone (NZGHGI 2023).

Traditional beef cattle emit 10.09 kg $CO_2$-e per kg of live weight (LW), with methane being the primary GHG. Although the number is increasing, dairy cows present a lower footprint of 6.88 kg $CO_2$-e per kg LW, 32% less than traditional beef due to shared emissions between milk and meat production (Mazzeto et al 2023). The combined average for beef stands at 8.97 kg $CO_2$-e per kg LW. Sheep meat and wool production results in a carbon footprint of 6.01 kg $CO_2$-e per kg LW, about 40% lower than traditional cattle. Transport emissions from cradle-to-grave (farm to processing plant) add approximately 5.8 kg $CO_2$-e per ton LW for cattle and 5.7 kg $CO_2$-e for sheep. Emissions from slaughtering these animals average 0.51 kg $CO_2$-e per kg of meat, primarily due to energy used during the process. Post-processing emissions contribute 1.7 to 6.5% of the total footprint, with export from New Zealand being the major source at this stage, accounting for 0.8–2.8% of the overall emissions

(Mazzeto et al 2023). With over 10 million cows and 26 million sheep leaving the largest carbon footprint in the country, mitigating the levels of GHGs from livestock is a priority. The NZ Government proposed to tax farmers based on their herd size which became known as the "Cow Burp Tax" (Perry 2022). The NZ Government is focusing on enteric fermentation, as well as methane being released from the waste sector through a category they refer to as biogenic methane. While the levy on farmers has not yet passed, the Zero Carbon Amendment Act of 2019 is a policy which targets a 10% reduction of biogenic methane from 2017 levels by 2030, and 24 -47% reduction by 2050 (NZG 2019).

The Climate Implications of Policy Assessment, instituted in 2019, mandates the consideration of GHG emissions impacts in all new policy proposals (NZG 2021). This approach aligns with New Zealand's broader climate strategy as outlined in the Zero Carbon Act. The Act responds to the Paris Agreement, establishes a framework for the nation to develop and implement clear, stable climate change policies, including the establishment of the Climate Change Commission (CCC). The CCC plays a crucial role in monitoring the progress towards emissions reduction targets set for 2050, which include a target for net zero emissions of all GHG's except biogenic methane (NZG 2021; Semmelmayer 2020). NZ is also investing in decarbonization and research initiatives, as demonstrated by the government's investment in the Decarbonizing Industry Fund (GIDI) and its leadership in the New Zealand Agricultural Greenhouse Gas Research Center. These initiatives, along with the adoption of emissions budgets, highlight the nation's commitment to adopting energy-efficient and renewable technologies across all sectors to reduce emissions (NZG 2021). However, the analysis also suggests the need for more strict enforcement and greater integration of Māori interests in future policy development to enhance the effectiveness of these strategies. While NZ's policies, NDC's, and efforts towards decarbonization are positive, implementing the changes has proved challenging (Semmelmayer 2020).

The CCC has identified over 1 million hectares suitable for afforestation, although several programs support this advisement, not many trees have been planted (NZG 2021; Kaine et al 2023). The CCC plans to manage different adaptations and mitigations to the various challenges that climate change is likely to bring. The Zero Carbon Act is widely supported by the public; however, political, legal, and economic professionals have criticized it. A method being questioned is the Emissions Trading Scheme, implemented as the New Zealand Unit (NZU) (Semmelmayer 2020). NZU's are essentially a permit to produce GHG emissions that can be purchased by businesses. The reform of New Zealand's Emissions Trading Scheme (NZ ETS) through the Climate Change Response (Emissions Trading Reform) Amendment of 2020 introduces tools for reducing emissions and meeting the Paris Agreement targets. NZ ETS mandates businesses measure and report GHG emissions, pay 1 NZU to the NZ Government per ton of $CO_2$-e, and limit the amount of NZU's available to each company. The effectiveness of the NZ ETS has yet to prove sufficient to mitigate enough GHG's to meet the targets set in the Paris Agreement (NZETS 2023; Semmelmayer 2020). According to the Climate Action Tracker, although NZ is doing better than some other developed nations regarding fossil fuel use, their methods are still insufficient to meet the target goals.

New Zealand's approach to mitigating the impacts of ACC is continuing to evolve. Creating a strategic framework towards eliminating GHG emissions, a Climate Change Commission for monitoring progress, an Emissions Trading Scheme, and ambitious, although potentially insufficient, Nationally Determined Contributions are a solid foundation for decarbonization. Challenges will continue as NZ finds a way to balance economic growth and implementing a variety of adaptations and mitigations (Semmelmayer 2020). The Nation's very achievable commitment to a 100% renewable electric grid by 2050, and the focused analysis on the dairy industry highlight New Zealand's stance on climate change. The obstacles for achieving afforestation targets, reducing synthetic nitrogen fertilizer use, and managing livestock highlight the need for more innovative approaches and policies to meet international climate commitments. While New Zealand develops ways to mitigate and overcome the complex impacts of ACC, it's investment so far aligns with the global commitment to reduce carbon emissions. Only time will tell if the commitments are sufficient.

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