IN THE WAITANGI TRIBUNAL **WAI 2607**

IN THE MATTER OF The Treaty of Waitangi Act 1975

AND IN THE MATTER OF A claim by **Tāne Cook** on behalf of **Maatatua District Māori Council** that the Crown is acting in breach of Treaty of Waitangi obligations towards Māori as a result of the New Zealand Government failing to implement adequate policies to address the threats posed by global climate change.

FURTHER EVIDENCE OF IVO GEOFFREY BERTRAM

Dated 14 August 2026

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1. Introduction

1.1 My name is Ivo Geoffrey Bertram. I live in Wellington and am an economist.

1.2 I have previously provided for this inquiry evidence dated 24 August 2024 (#A5), 28 April 2025 (#A5(a)) and 16 May 2026 (#A5(b)).

1.3 When I last appeared before the Tribunal on 27 May 2026 I said that I would provide relevant academic papers on economic forecasts of future damages caused by climate change.

1.4 Since I gave my evidence I have become aware of a crucial new piece of relevant work appearing as the lead article in the May 2026 issue of *Quarterly Journal of Economics* (one of the mainstream profession's top two or three journals). This is the paper by Adrien Bilal and Diego R. Känzig[1] titled *The macroeconomic impact of climate change: global versus local temperature*, a copy of which I have provided with my evidence.

1.5 Previous academic papers worked with damages estimates of the order of 1-3% of GDP loss for 1 degree of warming. This approach is set out in the paper by William Nordhaus[2] which I mentioned when I last gave evidence. The new paper completely overturns those statistical results, finding a 20-30% loss of GDP per 1 degree of temperature rise, with a more-than-50% central estimate for per capita GDP loss if temperature rises 2 degrees by 2100.

1.6 The reason these big numbers have suddenly come into view is that the new modelling works on global data rather than country-by-country data, and so picks up the long-run effects of ocean temperature changes and distribution of climate shocks across all countries. The key hypothesis (page 917) is that "global temperature shocks are inherently different from local temperature shocks and capture potentially damaging climatic implications that local temperature does not."

1.7 This paper is a likely game-changer for the economics profession[3], which has to date relied on the estimates of only modest impacts on GDP of climate change in previous academic papers.

1.8 Given the significance of this new academic work I have been preparing an academic paper on its impact upon the approach to estimating the GDP impacts of climate change in New Zealand. I am in the process of getting my draft paper peer reviewed but given the pressing need to have my evidence filed in the Waitangi Tribunal I provide below the parts of my present analysis which seem relevant to the issues presently being addressed by the tribunal.

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1 A. Bilal and D.R. Känzig, The macroeconomic impact of climate change: global versus local temperature, *Quarterly Journal of Economics* 141(2): 889-944 (2026).

2 W. Nordhaus 2018, Projections and Uncertainties about Climate Change in an Era of Minimal Climate Policies *American Economic Journal: Economic Policy* 10(3): 333–360.

3 The Bilal and Känzig paper first appeared in May 2024 as NBER Working Paper 32450. As of August 2026 it has accumulated 471 citations according to Google Scholar.

2 Background

2.1 I have been asked to provide background information on the techniques used by economists to estimate the costs that present-day emissions of greenhouse gases (GHGs) impose on future generations by causing climate change.

2.2 Mainstream economics brings to this question a well-established set of techniques for evaluating, in monetary terms, those costs and benefits of an action or policy that are capable of such quantification. This procedure has provided numerical benchmarks that policymakers have used in setting carbon taxes or pollution charges, but it has become increasingly apparent that the resulting estimates of the cost of climate change have been too low, and policy consequently has been too unambitious in addressing the need to reduce GHG emissions.

2.3 There are two reasons why the early rounds of economic work on the social cost of carbon (SCC) have produced results at or below the lower bound. First is the failure to fully account for non-monetary and non-monetisable damage to the environment and to human society[4]. In this regard, the 2017 High Level Commission (led by Joseph Stiglitz and Nicholas Stern) has stated[5]:

> …many of the impact functions used in modeling exercises to calculate the SCC are biased downward because they fail to consider many vitally important risks and costs associated with climate change … particularly the widespread biodiversity losses, long-term impacts on labor productivity and economic growth, impacts on the poorest and most vulnerable, rising political instability and the spread of violent conflicts, ocean acidification, large migration movements, as well as the possibility of extreme and irreversible changes.

2.4 A review of the 2022 South East Queensland rainfall and flooding events, for example, suggested that 'non-tangible' costs (physical and mental health, social and community impacts) could be as big or even bigger than 'tangible' costs (damage to residential, commercial and public infrastructure, lost economic activity, emergency response and clean-up). This research showed that health, social and community impacts can form the biggest share of economic impacts, driven by effects on mental health, chronic disease, and family violence.[6] Another non-monetary cost that has been missed in

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4 For an indication of how much of the scientific evidence of non-monetary impacts on a wide range of environmental and societal values is missed in economic models, one can contrast the extensive 2022 discussion of those impacts in the IPCC Sixth Assessment Round Working Group II report at https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FullReport.pdf with the restricted range of issues addressed by the Economic Cross-Working-Group report embedded within Chapter 16 of that report (https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-16/).

5 Carbon Pricing Leadership Coalition. (2017). *Report of the High-Level Commission on Carbon Prices*. Retrieved from Washington, D.C.: https://ipdcolumbia.org/publication/report-of-the-high-level-commission-on-carbon-prices/

6 Deloitte. *The social, financial and economic costs of the 2022 South East Queensland Rainfall and Flooding Event*. 2022. https://www.qra.qld.gov.au/sites/default/files/2022-07/dae_report_-_south_east_queensland_rainfall_and_flooding_event_-_8_june_2022.pdf, cited in He Pou a Rangi/Climate Change Commission, *Progress report: national adaptation plan* August 2026 https://www.climatecommission.govt.nz/assets/Uploads/CCC-6270-NAPPA-2026_FA_WEB-2807.pdf p.5.

economic modelling to date is deaths due to wildfire smoke. A recent paper in *Nature* finds that "[p]rojections show a surge in the number of premature deaths from wildfire smoke, reaching 1.40 (95% confidence interval = 0.66–2.25) million people annually during 2095–2099—roughly six times higher than current levels."[7]

2.5 The second reason for low values of the estimated cost of carbon emissions is the difficulty of obtaining statistically-significant estimates of how changes in global temperature affect the world economy, along with an early tendency towards adoption of discount rates of 3-5% rather than the now-common 2% or less. These issues are the subject of the remainder of this evidence.

2.6 Focusing on what can be monetised leads naturally to adoption of worldwide Gross Domestic Product per capita (GDP_{pc}) as the key magnitude – one for which present-day and historic values are available, and for which future paths can be projected by economic modellers, with and without the anticipated climate change impacts from changes in the atmospheric concentration of GHGs. The welfare of future generations is then equated with the level of consumption spending that can be sustained out of future $GDP_{pc,}$ and the welfare impact of climate-change damage is equated with the amount of future GDP_{pc} (and hence consumption) that is sacrificed as a result of present-day GHG emissions. The well-known deficiencies of GDP as a measure of human wellbeing are set aside for the purpose of producing numerical results.

2.7 The first step in this analysis is to construct two hypothetical future paths of GDP_{pc} for the world economy – one under today's atmosphere (the "base case"), and one with a higher atmospheric loading of GHGs. The difference between the two then represents the year-by-year future economic damage attributed to climate change. This is the "damages function" - the relationship between degrees of emissions-driven warming and percentage loss of annual GDP_{pc}.

2.8 The second step is to convert that time-series of future costs into a present-day value, using a discount rate. This produces a single dollar number, the SCC, representing the estimated future economic damage inflicted on society by any action that causes an additional tonne of carbon dioxide to be emitted today. This SCC then becomes the value that today's decision-makers are supposed to place on the lost welfare of future generations.

2.9 For any given damages function, a high discount rate will give a low SCC, and vice versa. In the extreme, a zero discount rate would give equal weight to all future generations alongside the present, which would mean that the SCC would tend towards infinity and the policy prescription would be an immediate halt to net GHG emissions. In contrast, a discount rate of 10% or more would mean that damage just a decade into the future would count for less than half as much as a present-day cost or benefit.

7 M. Qiu, J. Li, C.F.Gould, R. Jing, M. Kelp, M.L.Childs, J. Wen, Y. Xie, M. Lin, M.V. Kiang, S.Heft-Neal, N.S. Dieffenbaugh, and M. Burke, Global warming amplifies wildfire health burden and reshapes inequality, *Nature* : 935-943 (2025), p.935.

2.10 Until recently, the application of these techniques by mainstream economists tended to produce low numbers for monetised damage, and hence for the SCC, which has set a low bar for carbon charges or taxes. The DICE model developed by William Nordhaus has, for example, consistently produced numbers for the SCC of the order of US$30 or less per ton of CO2 emissions[8]. Nevertheless, as the economic research frontier has advanced since the early 1990s, estimates of economic damage from GHGs, and of the social cost of carbon, have increased, especially in the last decade.

2.11 Initially most published numbers for the SCC were very low - some near zero[9]. Around 2010 attention turned to possible "fat tails" in the probability distribution of estimated damages - that is, possible extreme or catastrophic damage, albeit predicted with low probability[10]. Since about 2015 published damage estimates have been rising, and the SCC has increased accordingly. SCC estimates running to hundreds of dollars per tonne of CO2 emissions are now common (see, for example, paragraph 3.3 below), and numbers over US$1,000 per tonne have begun to appear in the peer-reviewed literature.

2.12 To obtain projected paths for GDP_{pc} with and without additional GHG emissions, economists use "integrated assessment models" (IAMs) which link greenhouse gas emissions, and the consequent changes in their atmospheric concentration, to estimated changes in GDP_{pc} via impacts on temperature, hence on climate, hence on the productive capacity of the economy, and hence on GDP_{pc}.

2.13 There is strong scientific evidence for the first of these links, from emissions to temperature, but the next step - the impact on GDP_{pc} of global temperature changes - has been a weak link in the IAM chain. Until very recently the relationship of GDP_{pc} to temperature was estimated by cross-section statistical regressions using paired observations of GDP_{pc} and temperature at different geographical locations around the world, with the resulting equation used to project future changes in GDP_{pc} as temperature rose.

2.14 There were always two problems with this approach.

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8 See for example W. Nordhaus, Projections and uncertainties about climate change in an era of minimal climate policies, *American Economic Journal: Economic Policy* 10(3): 333–360 (2018) Table 6 p.357. This shows SCC estimates of US$23.87/ton for DICE-2013 and US$33.62/ton for DICE-2018, along with far lower estimates from several other economists' models.

9 For example R. Mendelssohn, *Climate change and economic growth*. Working Paper 60, Commission on Growth and Development, Washington DC: World Bank, 2009. Mendelssohn argued (2009 p.8) that the Stern Report and the work of the IPCC were "largely alarmist and misleading. Although climate change is a serious problem that deserves attention, society's immediate behavior has an extremely low probability of leading to catastrophic consequences. The science and economics of climate change is quite clear that emissions over the next few decades will lead to only mild consequences."

10 The two economists most noted for this line of enquiry were Robert Pindyck and Martin Weitzman. M. L. Weitzman, On modeling and interpreting the economics of catastrophic climate change, *Review of Economics and Statistics* 91(1):1-1 (2009); GHG targets as insurance against catastrophic climate damages, *Journal of Public Economic Theory* 14: 221–244 (2012); Fat Tails and the Social Cost of Carbon, *American Economic Review* 104(5): 544-546 (2014). R.S. Pindyck, Fat Tails, Thin Tails, and Climate Change Policy, *Review of Environmental Economics and Policy* 5(2): 258–274 (2011); Uncertain Outcomes and Climate Change Policy, *Journal of Environmental Economics and Management* 63: 289–303 (2012).

2.14.1 First, it identified 13 degrees Celsius as the "optimum" temperature at which GDP_{pc} is maximised, so that applying the resulting equation meant that all departures from this (either up or down) would depress GDP_{pc} [11]. But as a well-known finding from development economics has shown[12], this largely reflects the modern historical reality that developed, high-income economies are primarily in the temperate zones, in contrast to a previous historical era before 1500 when the world's great civilisations and richest economies were in the tropics. Thus if the same statistical work had been done centuries earlier, it would have produced a different estimated damages function.

2.14.2 Second, comparing GDP_{pc} and temperature observations across space at the same time is a static approach that fails to capture dynamic processes operating through time. As the latest research is now showing, economists' very conservative economic estimates of the damages function, and correspondingly low numbers for the SCC, have been critically dependent on this weak statistical link in the first generation of IAMs.

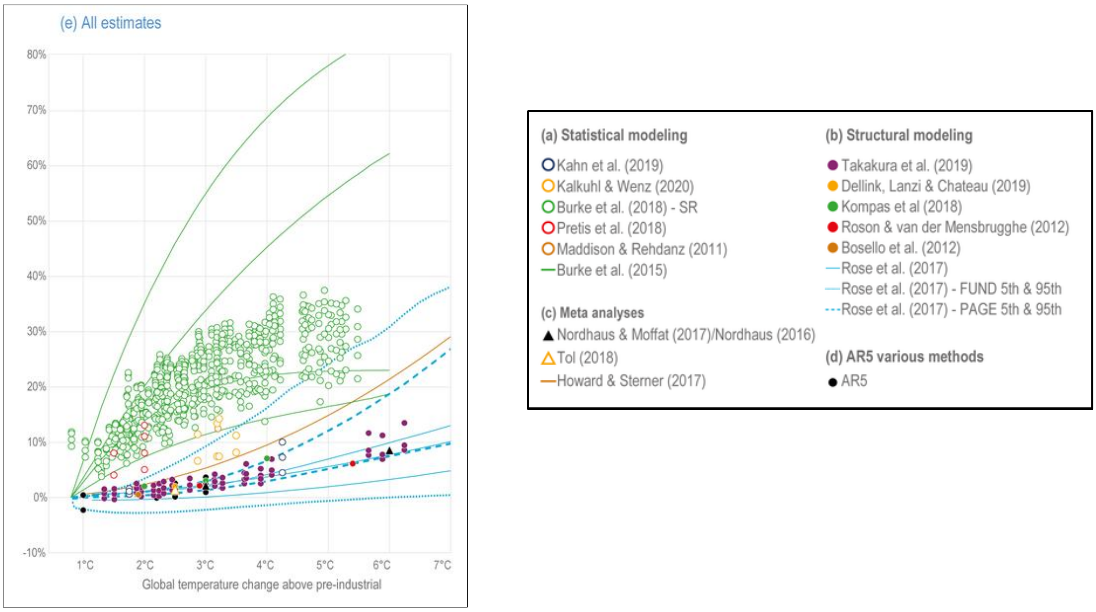
3 Evolving estimates of the damages function

3.1 The chart below is taken from the Working Group II report for the Sixth IPCC Assessment Round, published in February 2022[13]. It summarises the range of estimated damages functions in the published peer-reviewed literature up to 2020. At 2 degrees of global warming, the percentage loss of global GDP_{pc} (shown up the vertical axis) ranges from negligible up to 25%, with the bulk of published studies clustered at very low levels (only a few published papers at that stage had produced really high numbers) but with a "tail" of possible outcomes (the top green line in the chart, representing the upper limit of the statistical distribution of outcomes in Burke *et al* 2015) extending up to a 35% loss of GDP_{pc} at 2 degrees of warming.

11 M. Burke, S. M. Hsiang and E. Miguel, Global non-linear effect of temperature on economic production, *Nature* 527(7577): 235-239 (2015).

12 D. Acemoglu, S. Johnson and J.A. Robinson, Reversal of fortune: geography and institutions in the making of the modern world income distribution. *Quarterly Journal of Economics* 1231-1294 (2002).

13 https://www.ipcc.ch/report/ar6/wg2/downloads/figures/IPCC_AR6_WGII_Figure_16_Cross-Working_Group_Box_ECONOMIC-1.png accessed 6 August 2026.

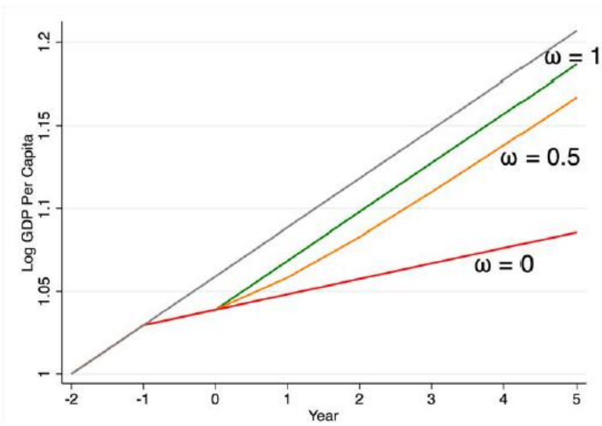


3.2 One key reason for this wide dispersal of damage estimates is described as follows in a 2024 paper (emphasis added)[14]:

> Estimates that follow from the seminal Nordhaus (1992) DICE model suggest that, in the no-abatement emissions scenario, temperature changes will cost the global economy approximately two to three percent of GDP in 2099. In contrast, a second strand of damage estimates that follow from the work of Burke, Hsiang and Miguel (2015) suggest that global warming will cost the world economy 20 to 30% of GDP in 2099. <u>The sharp divergence of estimates arises from disagreement over whether a permanent change in temperature will affect levels or growth rates of income in the long run.</u>

3.3 The authors of that 2024 paper presented a schematic diagram, reproduced below, to show the difference between a change in the level of GDP_{pc} and a change in its rate of growth[15].

(b) Growth Path Following a Permanent Shock in Year 0



14 I.B. Nath, V.A. Ramey, and P.J. Klenow, *How Much Will Global Warming Cool Global Growth?* NBER Working Paper 32761 July 2024, p.1.

15 I.B. Nath, V.A. Ramey, and P.J. Klenow, *How Much Will Global Warming Cool Global Growth?* NBER Working Paper 32761 July 2024, p.9 Figure 1(b).

3.4 The grey line in this chart shows the projected trend of GDP_{pc} in the absence of a climate shock. In “year 0”, GDP_{pc} drops below its trend (along the red line) as a direct result of an increase in global temperature.[16] Thereafter, three possible stories can be told:

3.4.1 The green line labelled ω=1 shows GDP_{pc} returning to its previous growth rate, but staying a constant amount below the baseline – in other words, the temperature increase means a lower level of GDP_{pc} in each year, but leaves the long-run growth rate unchanged.

3.4.2 The red line labelled ω=0, in contrast, treats the fall in GDP_{pc} in year 0 as due to a reduction in the global economy’s long-run growth rate, which remains lower than the baseline from then on. The hypothesis is that GDP_{pc} grows more slowly at higher global temperatures, so that the annual damage (foregone GDP_{pc}, measured as the distance between the grey baseline and the red line) increases inexorably over time.

3.4.3 In between, the yellow line ω=0.5 shows the growth rate falling for some number of years before returning to its previous rate, producing an intermediate amount of damage over time.

3.5 Nath *et al* 2024 presented evidence in support of the ω=0.5 hypothesis - a persistent, but not permanent, impact on the rate of growth. They then calculated three estimates of the possible percentage loss of global GDP_{pc} in 2100[17], under the IPCC’s RCP8.5 warming scenario[18]. They found damage by 2100 of 2% of GDP_{pc} under a “levels” model, 26.6% under a “growth” model, and 7-12% under their preferred intermediate scenario. These results “impl[ied] impacts in 2099 that are three to five times larger than contemporaneous level effect estimates, but one-half to one-fourth as large as estimates based on permanent growth effects”[19]. A less extreme warming scenario than RCP8.5 would obviously have yielded smaller damage numbers under all three scenarios, while leaving intact the dramatic difference between “levels-based” and “growth-based” estimates.

3.6 Since then an important newly-published paper[20] has shifted the picture sharply towards higher damage estimates, by focusing on the statistically weak relationship

16 In practice, obviously the expectation is that temperature will increase steadily rather than in the one-off shock applied to obtain estimated damage in these models. The future path of damages is thus to be thought of as a cumulative sequence of small shocks, each bringing its own contribution to the global total damage function.

17 Nath et al 2024 p.42 Table 4.

18 This was the “worst case” scenario used by the IPCC in its Fifth and Sixth Assessment Round reports. It is now - as of 2026 - generally rejected as too extreme. It projected temperature increases for individual countries at 2100 ranging between 2.7 and 5.8 degrees of warming, with a global average of 3.7 degrees.

19 I.B. Nath, V.A. Ramey, and P.J. Klenow, *How Much Will Global Warming Cool Global Growth?* NBER Working Paper 32761 July 2024, p.45.

20 A. Bilal and D.R. Känzig, The macroeconomic impact of climate change: global versus local temperature, *Quarterly Journal of Economics* 141(2): 889-944 (2026).

between temperature and GDP_{pc} in previous IAMs, and producing a more solid, but more worrying, statistical analysis of that link.

3.7 This latest work uses time-series regressions to estimate how individual countries' GDP_{pc} has been affected by changes in global temperature over the past two centuries, and then aggregates these country-level effects up to global GDP_{pc} changes. Two regressions are used: one covering 43 countries from 1860 to 2019, a span of 160 years, and the second covering 173 countries for six decades from 1960 to 2019.

3.8 Because this is time-series analysis, rather than the static cross-section and panel data used in previous IAMs, the authors are able to capture time lags and long-run impacts of identified temperature changes, both up and down, and to use these results to make projections forward to 2100. They find that over the past century and a half, 1 degree of global warming has been statistically associated with a 20% reduction in GDP. Projecting global temperature forward to reach 2 degrees of additional warming over 2024 by 2100[21], they find (pp.933-934) a GDP_{pc} loss of 53% and an associated SCC of $1,200 per ton, with a 95% confidence band from $399 to $2,105, using a time-preference rate of 2%.

3.9 Two important features of these new results deserve emphasis here.

3.9.1 The first is that because the model is a dynamic one based on time-series analysis, it incorporates both "level" and "growth-rate" effects of temperature changes, and hence directly resolves the tension between the two that was the subject of the 2024 Nath *et al* paper[22]. Bilal and Känzig find (p.935) that "climate change reduces the world growth rate by as much as a third of baseline growth in the twenty-first century" so that a lower rate of growth of GDP_{pc} is fundamental to their high damages numbers.

3.9.2 The second feature is that the size of the link from temperature to GDP_{pc} has turned out dramatically bigger in magnitude than in the previous IAM estimates. The reason for this is evidently that the new statistical analysis relates GDP_{pc} in individual countries to changes in global temperature, rather than the country-specific temperature levels used in previous cross-section and panel regressions. This means that country-specific climate detail is replaced by global temperature levels, which (i) goes to the heart of the climate-change issue, given that it is a global phenomenon, and (ii) enables non-terrestrial elements of the story – especially the oceans – to enter the picture. The omission of ocean-related changes from previous IAM estimates may well have been crucial in

21 This is equivalent to 3 degrees above pre-industrial temperature, which makes the Bilal and Känzig scenario consistent with the range of temperatures projected in IPCC scenarios RCP4.5 and RCP-6.0, well below the RCP8.5 scenario used by Nath *et al* 2024.

22 Bilal and Känzig 2026 p.891 summarise their results thus: "In the broader [1960-2019] PWT sample, a global temperature shock scaled to 1ºC leads to a gradual decline in world GDP per capita that peaks at 14% after 6 years with a 95% confidence interval of (6%, 22%), and is statistically significant at the 5% level in years 2–8. In the longer [1860-2019] BU sample, the same temperature shock leads to a peak effect at 18% after 5 years with a 95% confidence interval of (6%, 30%), and is statistically significant at the 5% level in years 0–6. In both cases, effects do not fully mean revert even after 10 years."

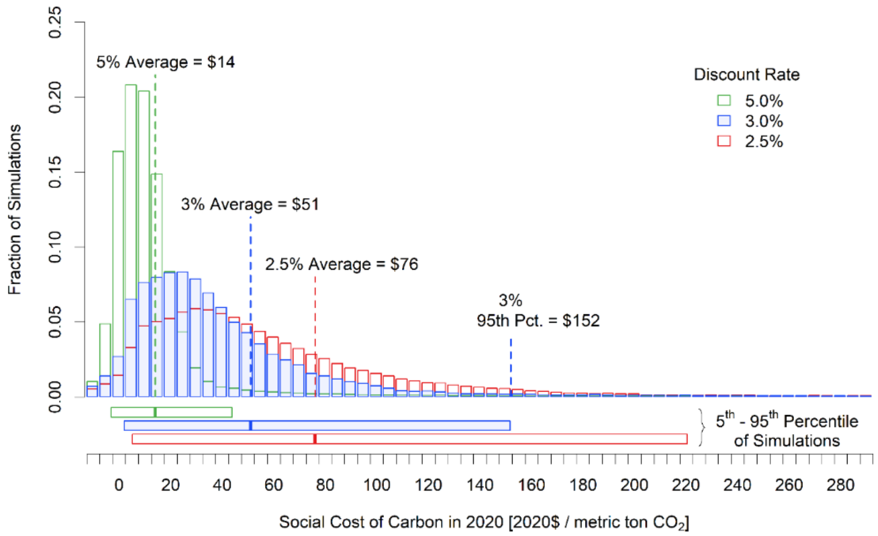
producing their much smaller estimates of damage and SCC. Bilal and Känzig argue that (2026 p.917) “global temperature shocks are inherently different from local temperature shocks and capture potentially damaging climatic implications that local temperature does not”.

3.10 Provided that these results prove robust when replicated by other researchers, they point to a sharply increased urgency of policy intervention to slow emissions, and suggest that the carbon price currently prevailing in the NZETS may be an order of magnitude too low.

4 The discount rate and the SCC

4.1 Discounting the damages function to a present-value SCC produces dramatically varying results as the discount rate changes. An example of this is the following chart from the 2021 US Inter-Agency Working Group report[23]

Figure ES-1: Frequency Distribution of SC-CO_2 Estimates for 2020[6]



4.2 The chart show the distribution of SCC numbers from a single IAM, discounted at three alternative rates. (The results from IAMs take the form of a range of estimates corresponding to 95% statistical confidence intervals, with a central number representing the mean value that is then reported as the result.) The effect of raising the discount rate is to reduce the weight of values in the more distant future, which truncates the distribution so that only damages suffered in the near future count significantly in the SCC number. The row for the year 2020 in the table below (from p.5 of the IWG report) shows the results plotted above: SCC mean values of US$14, US$51 and US$76 for discount rates of 5%, 3% and 2.5% respectively:

23 US Government Interagency Working Group on Social Cost of Carbon, *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide: Interim Estimates under Executive Order 13990* February 2021, https://downloads.regulations.gov/EPA-HQ-OAR-2023-0434-1026/content.pdf p.7.

Table ES-1: Social Cost of CO_2, 2020 – 2050 (in 2020 dollars per metric ton of CO_2)[3]

	Discount Rate and Statistic			
Emissions Year	5% Average	3% Average	2.5% Average	3% 95th Percentile
2020	14	51	76	152
2025	17	56	83	169
2030	19	62	89	187
2035	22	67	96	206
2040	25	73	103	225
2045	28	79	110	242
2050	32	85	116	260

4.3 In 2023 the US Environment Protection Agency produced a new set of estimates incorporating "recent research" that had been excluded from the 2021 IWG exercise[24]:

Social cost of carbon

EPA Final Estimates (2020$ per metric ton of CO2)

Year of Emissions	2.5% Discount Rate	2% Discount Rate	1.5% Discount Rate
2020	120	190	340
2025	130	210	360
2030	140	230	380
2040	170	270	430
2050	200	310	480
2060	230	350	530
2070	260	380	570
2080	280	410	600

Social Cost of Methane

EPA Final Estimates (2020$ per metric ton of CH4)

Year of Emissions	2.5% Discount Rate	2% Discount Rate	1.5% Discount Rate
2020	1,300	1,600	2,300
2025	1,600	2,000	2,700
2030	1,900	2,400	3,200
2040	2,700	3,300	4,200
2050	3,500	4,200	5,300
2060	4,300	5,100	6,300
2070	5,000	5,900	7,200
2080	5,800	6,800	8,200

24 https://costofcarbon.org/epa-values-for-the-social-cost-of-greenhouse-gases accessed 8 August 2026, based on the final EPA report at https://www.epa.gov/system/files/documents/2023-12/epa_scghg_2023_report_final.pdf .

4.4 The US Government’s 2023 adoption of a 1.5%-2.5% range with 2% as the preferred central rate represents a downward shift from the 3-5% range that had been standard in US policy debate around 2010[25]. There is, however, an ongoing debate over the appropriate discount rate which means that it is important, in interpreting any published SCC figure, to know the discount rate with which it has been calculated.

4.5 One common discounting approach uses what is called the “Ramsey equation”, which combines two elements: first a pure rate of time preference reflecting the ethically-based preference for the present over the future (this can be set to zero, to give equal ethical weight to present and future generations) and second, a “consumption discount rate” to reflect the expectation that future generations will live in a more prosperous economy. Insofar as economic growth might be halted or reversed by climate change, the rationale for this consumption discount rate would weaken. The current widespread use of a 2% discount rate in SCC calculations rests upon the assumption that per-capita consumption will grow over time.

4.6 Applying any single discount rate to the entire stream of future climate damages implicitly attributes certainty to that expectation of positive long-run growth of GDP_{pc}. When there is uncertainty over the future, one response can be to vary the discount rate used for different periods. In particular, there is a strong case for applying a discount rate that starts from a current consumption discount rate of around 2% but falls over time to lower levels for the very distant future.

5 The fat tail in the literature

5.1 A major 2024 review of the preceding two decades of economic studies, covering 147 peer-reviewed publications containing 1,834 estimates of the SCC, included a post-publication survey of 174 authors of those papers which revealed that by a wide margin, those authors regarded their own published numbers as having been too low[26]. Nevertheless an important feature of the published results, captured by the chart below, was the way that, despite clustering in the range of values from zero to US$100, the projected damages (represented by the SCC numbers) exhibited an extremely wide statistical-significance range on the upside, up to at least US$1,100 per ton of emissions. This is the “fat-tail” issue earlier identified by Pindyck and Weitzman (paragraph 2.11 above).

25 An extensive discussion of the issues and literature is in the 2021 IWG report file:///C:/Users/Owner/Downloads/EPA-HQ-OAR-2023-0434-1026_content.pdf pp.16-22.

26 Moore F.C. et al, Synthesis of evidence yields high social cost of carbon due to structural model variation and uncertainties, *Proceedings of the National Academy of Sciences* 121 (2024) https://www.pnas.org/doi/epdf/10.1073/pnas.2410733121 , p.5.

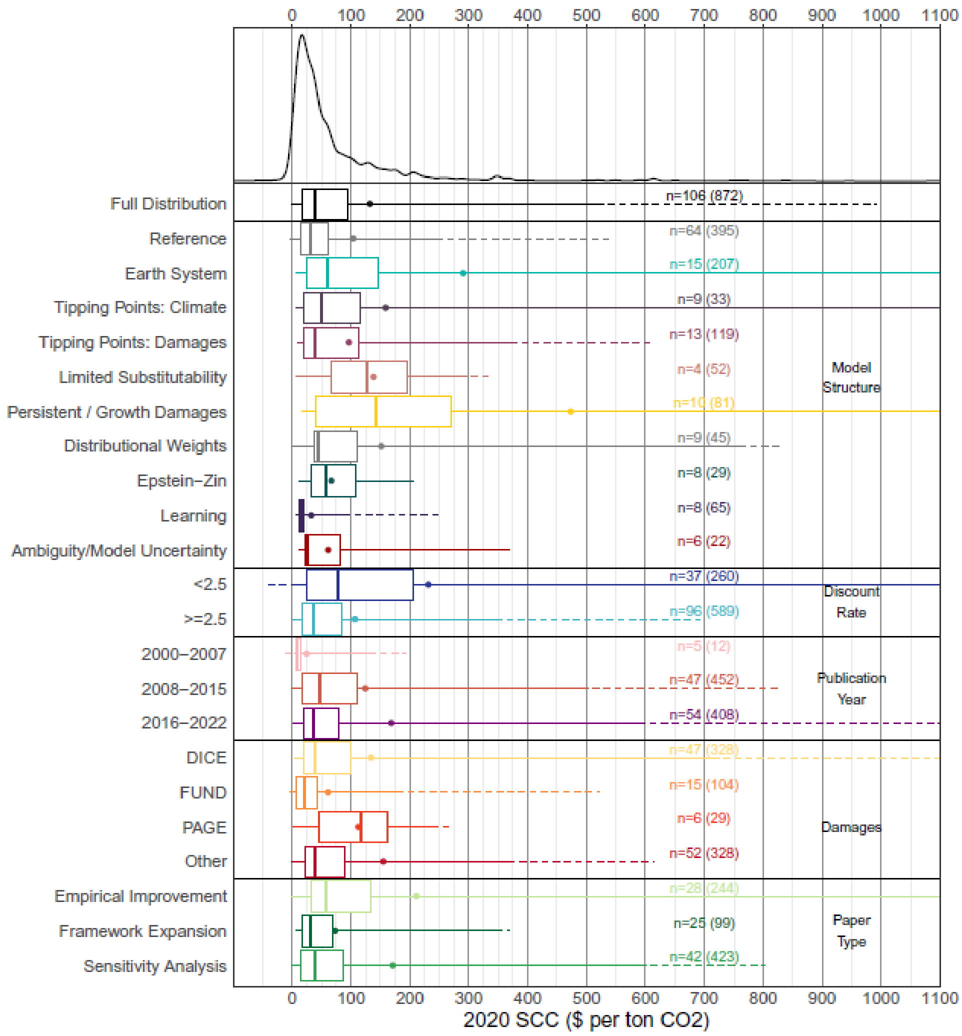


Fig. 1. Distribution of the 2020 SCC from the published literature (2020 $ per ton CO_2). Distribution and top boxplot show the distribution of all 2010 to 2030 SCC values (which we treat as the 2020-equivalent sample) from the published literature (equal weighting of all 147 papers). Other boxplots show subsets of the 2010 to 2030 distribution split by characteristics of published estimates, specifically model structure (see *SI Appendix*, section S3 for model structure descriptions and examples), discount rate, publication year, damage function, and paper type. The reference distribution refers to SCC estimates coded as not having structural changes, similar to the DICE model (versions up to 2016). Boxplots show the median (line), interquartile range (box), 5 to 95% range (solid line), and 2.5 to 97.5% range (dashed lines). Dots show the mean after trimming the upper and lower 0.1% of each distribution. Numbers for each plot show the number of papers and, in parentheses, the number of estimates included in each boxplot.

5.2 The top panel of the chart shows the distribution of the SCC estimates, ranging from negative up to $1,100 per ton. Most estimates are clustered below $100/ton, with a median value of US$39/ton, but estimates up to and above $1,100 are found, especially in studies with tipping points, with growth (as distinct from level) damages, with low discount rates (below 2.5%), and in work published after 2015. The mean value of the SCC (shown by the round blobs on the lines) rises strongly with publication year, reaching over $150 for the 54 surveyed papers and 408 results published in the years 2016-2022.

5.3 This steady rightward shift over time in the SCC numbers, and substantial right-hand “tail” in the distribution of results, reflects the importance of bearing in mind the potential for really major damages to occur if tipping points in the climate system are crossed.

5.4 Any numerical quantification of future damages can only cover areas where there is information that allows identification of the links from climate to the economy and society. As progressively more comprehensive and alarming scientific information on climate impacts has become available[27], it has fed into increasing social cost estimates.

6 Application to Aotearoa/New Zealand

6.1 The estimates of the damages function and SCC reviewed to this point have been drawn from the international literature, and are calculated on a global basis, because climate change is a global phenomenon. Each tonne of GHG emissions has the same long-run impact on the climate and on human society, regardless of where in the world it is emitted, so that New Zealand's emissions impose the same costs on humanity as all other countries' emissions. Hence the global SCC is the relevant benchmark for placing a monetary value on New Zealand emissions from the point of view of the global human community. For Aotearoa/New Zealand to remain a credible participant in international processes of cooperation on climate change, the global social cost of carbon is the relevant measure for local policy makers.

6.2 Those global costs, once incurred, do not fall equally across all countries. The damage to New Zealand's GDP_{pc}, from any given amount of atmospheric carbon and consequent temperature change (and hence the share of the SCC of each tonne of emissions that comes back as a cost to the local economy, as distinct from falling on other countries) should in principle be able to be derived from top-down disaggregation of the global damages function, to obtain the cost to the New Zealand economy from additional global GHG emissions, and hence the benefit to the local economy of any reduction in global emissions relative to their business-as-usual path.

6.3 However, while the IAMs reviewed in previous sections of this paper, with their statistical analysis of the relationship between temperature and GDP_{pc} based on country-by-country data, potentially yield country-specific damage and SCC estimates, there are three clear problems that mean the results from such an exercise could be misleading:

6.3.1 The world economy is an integrated system in which countries are linked together by trade, financial and population flows. Under serious climate-change stress, climate-related costs will inevitably spread across national borders, so that it is not safe to simply project one country's future economic damage from that country's own position in the datasets of past temperature and GDP_{pc} that were used to construct the big IAMs.

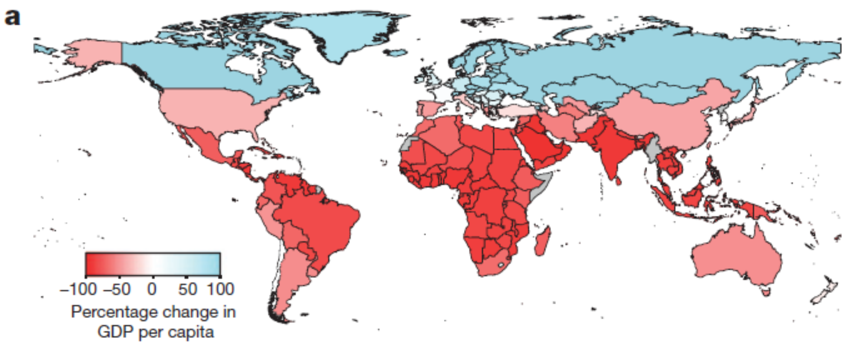
6.3.2 As has been pointed out in the most recent paper reviewed above (Bilal and Känzig 2026), almost all IAMs until recently have been based on analysis of

27 An illustration of this is the change over time in the so-called 'burning embers' diagram produced by the IPCC. Tipping points have gone from being estimated to be likely only at more than 3 degrees of warming to less than 2 degrees; see for example N. Keohane, *The IPCC's latest: As climate damages ramp up, the window of opportunity to adapt is closing fast*, February 2022, https://www.c2es.org/2022/02/the-ipccs-latest-as-climate-damages-ramp-up-the-window-of-opportunity-to-adapt-is-closing-fast/ accessed 14 August 2026.

paired data on local terrestrial (on-land) temperature and GDP_{pc} at specific geographical locations, which amounts to assuming that site-specific land temperature has been the key driver of local GDP_{pc} at each location (after statistical control variables have been taken into account in the regressions). This has had the effect of suppressing from view the local impacts of global temperature change and ocean temperature changes, which are likely to be more important than site-specific land temperature, once account is taken of the rise in extreme weather events attributable to ocean temperatures and global atmospheric circulation patterns.

6.3.3 GDP_{pc}, the monetary measure used in economic estimates of the damages function, does not incorporate a large array of non-monetary effects, and notoriously includes positive values for the cost of responding to natural disasters including those caused by future climate change. In using GDP_{pc} as their metric, economists have assumed that one way or another, the non-monetary effects will have found their way into the historic GDP numbers used in the IAM regressions. But, given that climate change has to date crept up slowly relative to what is coming in future, it is probable that regression analysis of past data – especially the static cross-section analyses in the early IAMs - will have failed to capture the exponentially-increasing physical damage to ecosystems and human societies indicated by the science, as reported in successive reports of the IPCC Working Group II. Changes that are likely in future but which have had little impact to date, such as a rising sea level leading to inundation of coastal lands, have been absent from the historical statistical record.

6.4 To see how these problems urge caution about simplistic top-down disaggregation of globally-estimated economic damage, consider how the IAM used in Burke *et al* (2015) maps the projected distribution of the global damage to GDP_{pc} in the year 2100 under what was then the worst-case IPCC scenario RCP8.5[28]:



New Zealand here emerges with virtually unchanged per-capita GDP_{pc} in 2100, while colder countries (Canada and Russia, for example) actually gain from climate change and the heaviest cost burden falls on Africa, India, Southeast Asia and tropical Latin America and the Caribbean. This result follows from that IAM's non-linear pattern of estimated effects on GDP_{pc}, with a 13-degree-Celsius "optimum temperature" derived

28 M. Burke, S. M. Hsiang and E. Miguel, Global non-linear effect of temperature on economic production, *Nature* 527(7577): 235-239 (2015), p.238.

from cross-section geographic regressions of GDP_{pc} on local temperature.

6.5 This depiction of zero or quite small GDP damage for New Zealand, with the bulk of the costs of this country's GHG emissions falling onto others, may help to account for the unwillingness of local policymakers to impose charges on polluters commensurate with the global damage they cause, given that the beneficiaries of reduced emissions seem to fall mostly elsewhere in the world leaving the New Zealand economy untouched. Yet already by mid-2026 there are clear emerging signs of substantial economic damage to Aotearoa/New Zealand from climate change – in particular an increased incidence of extreme weather events attributable to rising ocean temperature.

6.6 The Climate Change Commission is charged under section 5ZP of the Climate Change Response Act 2002 with preparation of a climate change risk assessment that is to "assess the risks to New Zealand's economy, society, environment, and ecology from the current and future effects of climate change". As the reference to "economy" indicates, the assessment potentially extends to estimation of a damages function, but does not explicitly require one.

6.7 The Commission's assessment was published in May 2026[29], evaluating 37 categories of risk across seven "domains" (interconnected systems): natural environment; built environment; people health and communities; things of importance in the Māori world; economy and finance; sectors relying on the natural environment; and governance. Two levels of global warming were modelled, based on, respectively, 2 degrees and 3-3.5 degrees of global warming by the end of the century.

6.8 In order to estimate future physical impacts, the Commission used data obtained by disaggregating global climate models, which as noted earlier are far more solidly grounded on scientific evidence than the economic damages functions derived from IAMs. This provided a detailed mapping, at territorial authority level, of physical impacts on climate variables such as rainfall, wind, humidity, drought, number of hot days and cold nights, and so on[30], to which was added coastal inundation. The full report extended to 390 pages of detailed enumeration of risks, and included monetary estimates of reduction in the value of certain classes of assets[31], but did not condense these details into GDP_{pc} numbers, let alone any sort of local-SCC number for New Zealand.

6.9 Various monetary estimates of the damages function for New Zealand have however been produced. For example in 2023 Deloitte estimated that "If there is inadequate action on climate change and the planet warms by 3ºC by the end of the century, New

29 He Pou a Rangi Climate Change Commission *Full assessment: 2026 National Climate Change Risk Assessment for Aotearoa New Zealand* May 2026 https://www.climatecommission.govt.nz/reports-and-evidence/publications/2026-national-climate-change-risk-assessment/ accessed 9 August 2026.

30 Detailed projections by territorial authority in dashboard form are at https://environment.govt.nz/facts-and-science/climate-change/climate-change-projections/climate-projections-summary-dashboard/ .

31 *Full assessment: 2026 National Climate Change Risk Assessment for Aotearoa New Zealand* Table 2.13 pages 56-57.

Zealand's economy could lose $4.4 billion of GDP by 2050, compared to projections that do not take into account the effects of climate change. These losses get exponentially worse beyond 2050."[32] The climate-change scenario modelled was described as "a future with a high rate of global GHG emissions, where current technologies and strategies reduce GHG emissions and stabilise the temperature increase at around 2°C by 2050 and 3°C by 2100. The modelling for this scenario reflects a widely adopted set of emissions, economic and population assumptions, referred to as SSP2-4.5."[33] Given that $4.4 billion represented just 1.1% of the 2023 value of GDP, this estimate for climate damages in 2050 after three decades of continued GDP growth implied a tiny damages function of far less than 1%.

6.10 Treasury modelling in 2021 estimated the GDP impact of two climate-change-related issues (droughts, and storms/floods) out to 2061 and produced the following charts[34], with central estimates well below 1% GDP reduction for each climate effect[35], though with extreme worst estimates of around 2% for drought and 3% for storms/floods:

Figure 18: Impact of increasing frequency of severe and moderate droughts on net debt and GDP

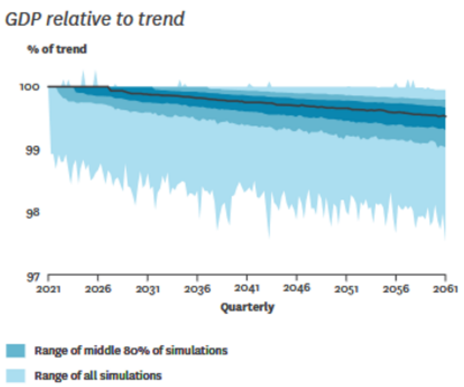
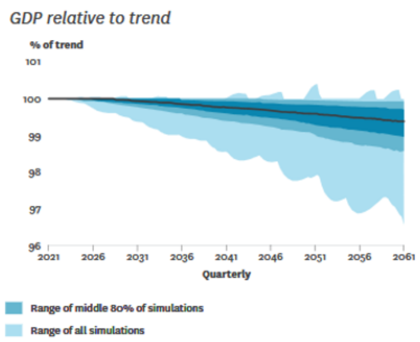


Figure 19: Impact of increasing storms and/or floods on net debt and GDP



6.11 These projected climate-related GDP impacts in the 0-3% range, with central estimates around 1%, are within the margin of error for any prediction of economic growth over the three decades to 2060 – in other words, they are tiny, and implausibly so unless the science is wrong.

6.12 Noting the recent sharp upward trend in economic estimates of the global damages function, it seems probable that a full economic accounting of the cost of climate

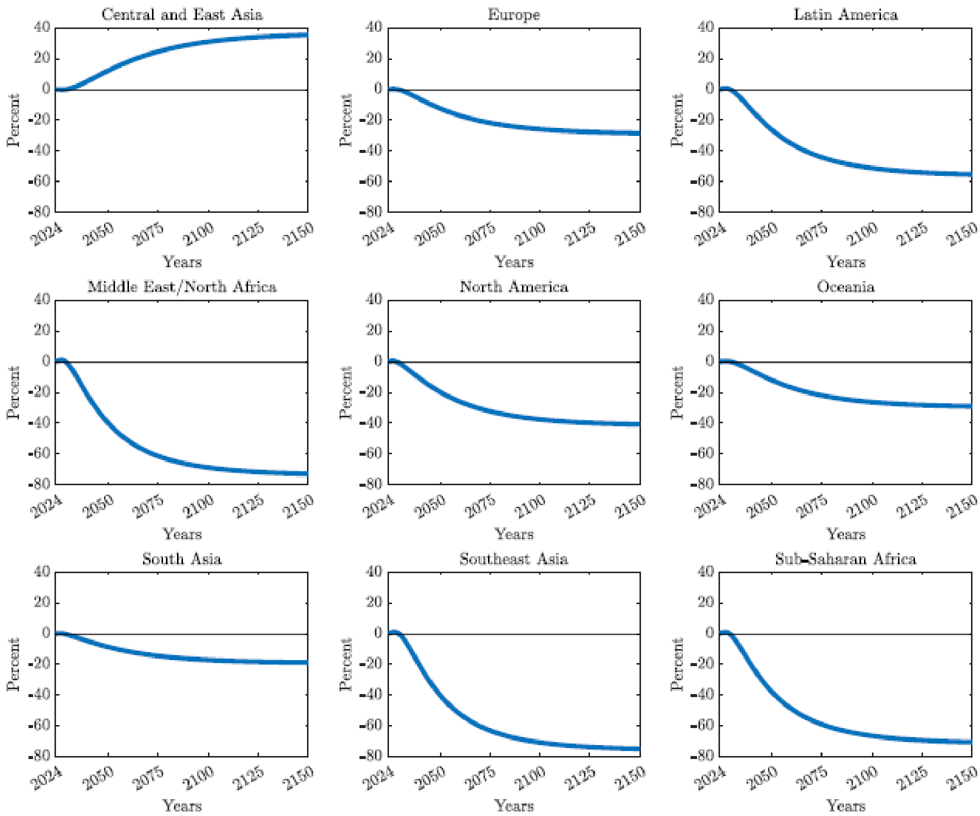
32 Deloitte, *Aotearoa New Zealand's turning point* March 2023, https://www.deloitte.com/content/dam/assets-zone1/nz/en/docs/services/financial-advisory/2023/nz-turning-point-report.pdf p.6.

33 Ibid p.16.

34 Treasury, *He Tirohanga Mokopuna 2021: The Treasury's combined Statement on the Long-term Fiscal Position and long-term insights briefing* , https://www.treasury.govt.nz/sites/default/files/2021-09/ltfs-2021_2.pdf , p.36.

35 Treasury and Ministry for the Environment, *Ngā Kōrero Āhuarangi Me Te Ōhanga Climate Economic and Fiscal Assessment 2023* https://www.treasury.govt.nz/sites/default/files/2023-04/cefa23.pdf p.40 summarised the 2021 results as follows: "The average of the modelled simulations showed the impact of increased drought frequency causing annual GDP to be 0.5% lower than the assumed trend by the final year of the simulation in 2061. By way of comparison, the impact of the 1997 to 1998 drought was estimated at 0.9% of GDP. The average of the modelled simulations showed the impact of increased storm/flood intensity as a 0.7% decrease in GDP compared to the assumed trend in 2061."

change for future generations of New Zealanders will yield larger damage estimates than those of Treasury and Deloittes. An indication of this is in the chart below, from the online appendix to the 2026 Bilal and Känzig paper[36] showing the projected losses of GDP_{pc} by region that aggregate to their projected 53% drop in global GDP_{pc} in 2100 under 2 degrees of additional warming relative to 2024:



GDP per capita counterfactuals for each region. Global mean temperature path from Figure XIII. Damage function estimated in PWT data.

FIGURE D.3: GDP per Capita for Each Region Under Global Warming

6.13 In the middle of that set, the chart for “Oceania” (Australia and New Zealand) shows a 30% loss of GDP_{pc} at 2100, similar to Europe though much less severe than the projected losses for Latin America, Southeast Asia, and Africa. That suggests a New Zealand damages function at least ten times bigger than the previous estimates reviewed above, and an SCC of several hundred US dollars per tonne.

36 https://oup.silverchair-cdn.com/oup/backfile/Content_public/Journal/qje/141/2/10.1093_qje_qjag011/2/qjag011_online_appendix.pdf?Expires=1789330318&Signature=4LveqXTQ4kRMRNKfZnOesrzIZVYYYrzXno2Onlt1BG5orpquGDh4Cie7beCDAvnbB413cki2AEW9uweLhU69ZwcNU~HOb6gfoYox2EikU3gGGQwXMunTqFOOmgASGhU-WIyYNixM7~qWN7usWJe48fUA9R8lS6PW-FTwHLtbQd51x2XsPAvS2DTKIwu11ARy3U0R9c87~yJxn0T3~aCNZebed1j74RYflvsmwCFV3qhaeosUMI7nZRVWiM1V5YdLs3WwriSPYYts0MbmKzL-9Y-DP9q8Z0EiZROUR6bQWyvksoShXm-fudE2Vn9ZvzIC0~aZkljxmKFZRxUTVBTtSg__&Key-Pair-Id=APKAIE5G5CRDK6RD3PGA p.102.

6.14 Considering how extensively the estimates of global damage have been revised upwards over time, it is clear that conventional estimates of the economically-measurable cost of carbon emissions to date have been too low, and that the outlook is for higher numbers to come over the horizon as experience with actual climate change accumulates. Adding in wider elements that are missed in the conventional economic analysis – equity issues such as impact on particular groups, obligations of the Crown under both Te Tiriti o Waitangi and international law, physical and mental health of affected populations, and potential collapse of ecosystems, to name a few – points strongly to the need for adoption of more ambitious measures to curb this country's emissions of GHGs.

Dated this 14th day of August 2026

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Ivo Geoffrey Bertram