Simulation modelling of tobacco endgame interventions and their impact on Māori:non-Māori health inequity in Aotearoa-New Zealand.

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Abstract

Background

Māori (Indigenous peoples of Aotearoa New Zealand [A/NZ]) have high tobacco smoking rates, a legacy of colonisation. We estimated the health gains and inequality reductions of the A/NZ Government's proposed endgame strategy implemented in 2023 of denicotinising tobacco, reducing retail outlets by 95%, and a making it illegal for people born after 2006 to purchase tobacco (tobacco-free generation).

Methods

A Markov smoking-vaping cohort model was parameterised for business-as-usual (BAU) using Health Survey data projections, and for endgame strategies using research and expert knowledge inputs. The difference in smoking and vaping prevalence between BAU and each endgame policies was merged with incidence rate ratios for 16 tobacco-related diseases and fed into a proportional multistate lifetable model to estimate future health-adjusted life years (HALYs) and mortality rates.

Findings

The combined package of strategies reduced adult smoking prevalence from 31.8% in 2022 to 7.6% in 2025 for Māori, and 11.8% to 2.8% for non-Māori. The 5% smoking prevalence target was achieved in 2026 and 2027 for Māori males and females, respectively.

The HALY gains for the combined package (compared to BAU) over the remaining lifespan of the A/NZ population alive in 2020 (5.08 million) was 598,000 (95%UI: 517,000 to 698,000; 3% discount rate). The denicotinisation strategy alone achieved 97% of these HALYs, the retail strategy 19%, and tobacco-free generation 12%.

The per capita HALY gains for the combined package for Māori were 4.75 and 2.14 times higher than for non-Māori females and males, respectively. The absolute difference between Māori and non-Māori all-cause mortality for 45+ year olds in 2040 was 22.9% (19.9% to

26.2%) less for females under the combined packaged compared to BAU, and 9.6% (8.4% to 11.0%) less for males.

Interpretation

A tobacco endgame strategy – especially denicotinisation – could dramatically reduce health inequities.

Funding

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Research in context

Evidence before this study

We searched publications listed in two systematic reviews of simulation modelling studies of tobacco control interventions published in 2021 and 2022, and additional publications known to the author team. We found nine publications, all from Aotearoa New Zealand, that reported equity impacts of modelled tobacco policies by ethnicity. Interventions modelled included: 1) mass media promotion of a smartphone smoking cessation app; 2) annual tobacco tax increases of 5%, 10%, 15% and 20% continued to 2025 and 2031; 3) tobacco free generation policy that bans tobacco sales to everyone born from 1993 onwards; 4) substantial reductions in the number of tobacco outlets including – reducing number of outlets to 5%, or 10% of the original number, restricting to 50% of alcohol outlets, prohibiting outlets within a 1 km, or 2 km radius of schools; 5) a sinking lid that gradually phased out all tobacco supply between 2011 to 2025; 6) restricting tobacco sales to pharmacies only with brief cessation advice provided to consumers; and 7) a mandatory very low nicotine standard for cigarettes (smoking prevalence in 2025 estimated). All studies suggested that all modelled interventions improved equity, of varying magnitude, in either smoking prevalence or health gain for Māori compared to non-Māori.

Added value of this study

Our sophisticated simulation model estimated the health gains by ethnicity for the Aotearoa New Zealand population alive in 2020 for their remaining lifespan for a package of policies that are included in the Government's Smokefree Aotearoa 2025 Action Plan, including: implementing a mandatory very low nicotine standard for cigarette in 2023 (or 'denicotinisation'); a 95% reduction in the number of tobacco retail outlets; and a smokefree generation law that prohibited the sale of smoked tobacco products to everyone born after the year 2006. We also identified which policies contributed the most to the health gains and the potential health equity impacts.

Implications of all the available evidence

Our findings indicate that this package of policies (denicotinisation, retail outlet reduction and a tobacco-free generation) would likely reduce smoking prevalence to less than 5% by 2025 for non-Māori females and males – but not for Māori. By 2027 all sex by ethnic groups would have a smoking prevalence of less than 5%. A 95% retail outlet reduction and a tobacco-free generation appear, on their own, are unlikely to achieve a 5% smoking prevalence for any sex by ethnic groups until at least 2040.

The impact of the combined package, or just denicotinisation, on improving Māori health status is profound, and greatly reduces Māori:non-Māori health inequality. For example, the combined package, compared to BAU, would reduce the absolute difference in 45 years and older all-cause mortality between Māori and non-Māori females by nearly a quarter.

No high-income country, particularly those with colonial histories, has yet implemented a comprehensive tobacco endgame strategy that includes both process and outcome measures with the goal of dramatically reducing health inequities. As such, evidence about how A/NZ's endgame strategy is implemented and the outcomes it achieves will provide important empirical evidence to inform action in other countries.

Introduction

Despite unequivocal evidence about the harm caused by commercial tobacco, it continues to be a leading cause of avoidable morbidity and mortality. Smoking prevalence in high income countries with colonial histories has steadily decreased over recent decades, but prevalence among Indigenous peoples is often substantially higher[1] than in the general population and is a significant contributor to health inequities.[2]

Indigenous people's experiences of colonisation include imposition of alien societal institutions, appropriation of economic resources and exposure to racism. Referred to as 'basic causes'[3,4] these affect access to social determinants of health (e.g. income, housing) and, via health behaviours such as smoking rates, ultimately lead to racialised health inequities. In many instances this has been compounded by the use of tobacco as a trade commodity. Since the late 19th century, tobacco companies have actively exploited and promote commercial tobacco to Indigenous peoples.[1,5,6]

In 2020-21, 22.3% of Māori (the Indigenous peoples of Aotearoa/New Zealand (A/NZ) 15 years and older smoked at least daily. This was 2.7 times the prevalence among European/Others (8.3%; NZ Health Survey). Life expectancy in 2017-19 for Māori was 77.1 years for females and 73.4 years for males, 7.3 and 7.5 years less than for non-Māori females and males, respectively.

Similar to other high-income countries, A/NZ's tobacco control programme includes: restricting the promotion of tobacco products; providing cessation support; implementing mass media campaigns; regular increases in tobacco excise tax; and smokefree area policies.[7] Many of these measures have some reliance on individual capacity and access to resources needed to carry out desired behaviours such as quitting cigarettes. These resources are inequitably distributed across the A/NZ population and for Māori compounded by additional exposures to basic causes, likely explaining a failure of A/NZs tobacco control programme to address smoking disparities. Concern about slow progress led Māori political and tobacco control leaders to propose a tobacco endgame in the mid-2000s. Instead of focusing on people who smoke, they argued that the tobacco industry and the products they sell should be targeted. In 2011 the A/NZ Government committed to achieving a Smokefree country by 2025[8] (commonly interpreted as less than 5% smoking prevalence among both Māori and non-Māori). Achieving this goal required a radical departure from business as usual (BAU) approaches [9], but actual tobacco control policy remained relatively unchanged. The 2010s coincided with the proliferation of alternative nicotine delivery devices and, in particular, electronic cigarettes, and introduced a discourse about 'harm minimisation' to the tobacco endgame debate.[10] A more holistic notion of 'harm' expressed among many Māori includes addiction as well as health harm, meaning that achieving an end to both nicotine addiction as well as tobacco smoking is the desired endgame.

The A/NZ Government launched an Action Plan in late 2021 to achieve the country's endgame objective.[11] This plan focused on smoked tobacco and sought to bring about rapid and profound reductions in smoking prevalence, and to do so equitably such that all population groups (in particular Māori) achieve minimal smoking prevalence by 2025. Three key ('endgame') strategies were identified in the Action Plan to achieve this goal: denicotinising retail tobacco to non-addictive levels (e.g., ≤0.4mg nicotine/cigarette)[12] markedly reducing retail access to tobacco and creating a 'Tobacco-free Generation'. The latter would be achieved by progressively raising the legal age at which tobacco can be sold to young people. These measures do not directly address basic causes or social determinants of smoking related inequities. However, they substantively circumvent the role of agency (e.g., individual access to necessary social or economic resources) in being able to quit smoking or resisting initiation. As such, they have strong potential to bring equitable change in smoking behaviour.[13] A challenge of these types of measures is that they would act against Indigenous aspirations of empowerment and self-determination[14] if they were enacted by a predominantly non-Indigenous government 'on' Māori. The Action Plan has sought to address this issue by seeking Māori engagement throughout the planning and policy development stages, including establishing a Māori Governance group.

Internationally, there is growing interest in endgame goals and strategies, with an increasing number of countries adopting endgame goals and a range of bold endgame interventions proposed. Countries such as Scotland have included a strong focus on equity within their endgame goals and strategies,[15] but, other than in A/NZ, a focus on Indigenous health inequities has not been a strong focus in countries' endgame strategies. Furthermore, the implementation of endgame interventions has been minimal and the evidence base is weak.[16] For example, none of the endgame interventions included in the A/NZ Action Plan have been implemented at country-level, with the possible exception of substantial reductions in retail supply in Hungary.

This paper aimed to estimate the future tobacco smoking prevalence, mortality and health adjusted life year (HALY) impacts (including changes in Māori:non-Māori inequalities) of tobacco endgame strategies outlined in the A/NZ Government's proposed Action Plan. Specific research questions were:

1. Which endgame strategies have the potential to reduce smoking prevalence to less than 5% for all sex and ethnic groups by 2025?
2. Which endgame strategies maximally reduce Māori:non-Māori health inequalities?

Methods

We adapted a tobacco simulation model[17] (rated as best of 25 tobacco models globally[18]), and expanded its capabilities to include a Markov smoking and vaping life history model and functionality for outputting packages of interventions and mortality rates by time.

Smoking and vaping life history model

We developed a Markov model to simulate population smoking and vaping behaviours, based on seven states (Supplementary Figure S1, Table S1): never smoker (NS); current smoker (CS); ever smoker current vaper (NSCV); dual user (DU); former smoker current vaper (FSCV); former smoker and/or former vaper (FSFV); never smoker former vaper (NSFV). Movement between states are determined by transition probabilities, which reflect BAU and the potential effects of interventions(below). Initiation of smoking (transition from NS to CS or DU) and vaping (transition from NS to NSCV) was assumed to occur at age 20 years. From the age of 20 onwards, any quitting of smoking was assumed permanent, parameterised as a 'net' cessation rate from CS and DU to either FSCV or FSFV. For proportions of the cohort in the FSCV state, there was an annual net transition probability to FSFV, but no return flow from FSFV to FSCV. The FSFV, FSCV and NSFV states were additionally modelled as 20-year tunnel states that the cohort progressed through each year, allowing the model to identify how many years each cohort was from quitting so as to incorporate decaying impacts of smoking on disease incidence by time since quit (see below).

To specify the transition probabilities under BAU, we first estimated future daily smoking (and vaping) rates by extrapolating trends in the 2013-14 to 2019-20 New Zealand Health Survey (NZHS) data, using a two-step regression approach: i) a best fit regression model to historic data; and ii) a regression model on the former predictions by sex,age and ethnicity to generate annual net cessation rates by cohort as they age, and annual trends in initiation.

We then calculated annual transition probabilities to achieve these projections, starting with transition probabilities between the seven states from the United Kingdom as reported by Doan et al.[19] (Supplementary Table S2), modifying them as required (with mathematical optimisation using Excel Solver) to meet the above projections. We performed this operation by sex and ethnicity for three age cohorts (20-24, 40-44, and 60-64), and interpolated other age cohorts.

Proportional multistate lifetable model

A proportional multistate life table (PMSLT) was used to estimate health impacts of smoking and vaping under BAU and intervention scenarios (key input parameters in Table 1). Briefly, the PMSLT is composed of a main cohort lifetable, which simulates the entire A/NZ population alive in 2020 until death using projected all-cause mortality and morbidity rates by sex, age, and ethnicity (Māori, non-Māori). In parallel, proportions of the cohort also reside in 16 subsidiary tobacco-related disease lifetables according to prevalence at baseline (i.e., start of model), and in future years based on BAU disease-specific incidence, case fatality and remission rates. Within each disease lifetable, morbidity estimates (i.e. disability rates from the NZ Burden of Disease Study[20]) are attached to prevalent cases. The tobacco-related diseases included in the model are: coronary heart disease, stroke, chronic obstructive pulmonary disease (COPD), lower respiratory tract infection (LRTI), and twelve cancers (lung, oesophageal, stomach, liver, head and neck, pancreas, cervical, bladder, kidney, endometrial, melanoma, and thyroid).

Within each disease lifetable, an intervention is run in parallel to BAU with different disease incidence rates given changes in smoking and vaping life histories (see next section). Each disease lifetable estimates the difference between intervention and BAU in disease mortality and morbidity rates that are then added to matching entities in the main lifetable.

Connecting the smoking-vaping life history model to the PMSLT – using population impact fractions

For each sex by age by ethnic group, and each annual time step into the future, a population impact fraction (PIF) is calculated for each tobacco-related disease. The generic formula[21] is:

$$PIF_{idt} = \frac{\sum_{j=1}^{n} P_j RR_{idj} - \sum_{j=1}^{n} P_j^{'} RR_{idj}}{\sum_{j=1}^{n} P_j RR_{idj}}$$

where: *i* subscripts each sex by age by ethnic group; d subscripts each disease; t subscripts each time step or yearly cycle; *j* subscripts each state in the smoking-vaping life history model; RR is the incidence rate ratio for disease d and smoking-vaping state *j*, and possible varying by demographics (e.g., by sex and age, but not by ethnic group; note the RR does not vary by time step *t*). These PIFs are the percentage change in incidence rates for each smoking related disease inputted to the PMSLT.

The source and values of the tobacco-related disease incidence rates and rate ratios are given in Appendices A-B and Supplementary Tables S3-S19. Harm from vaping was modelled as 5% to 20% of tobacco harm following Mendez and Warner[22] (Beta distribution with median 11% and 95% UI of 5% to 20%).

Interventions

To parameterise the intervention scenarios we adapted initial estimates by Wilson et al,[23] which derived their potential effects based on A/NZ-specific literature (including a randomised trial of denicotinised cigarettes) and international literature; adaptation for this paper included incorporating additional research and expert judgements by the authors. The intervention specifications are shown in Table 2. Briefly:

- Denicotinisation: initiation reduced to 10% of that in BAU by five years after implementation; cessation transition probabilities were increased so that over five years the smoking prevalence in CS and DU states was 15.2% of that in BAU, and from the sixth year onward cessation transition probabilities were doubled.
- Denicotinisation plus mass media: As above, plus an extra increase in cessation rates in the first five years of 2.1% (equivalent to twice the impact of past Quitline media campaigns in A/NZ on net cessation rates).
- Retail outlet reduction: we used the average of two inputs: a) previous modelling by ourselves [24] of increasing travel time, converted to cost and then through price elasticities that estimates a 15.8% reduction in smoking prevalence in the year of implementation; b) 23.0% of respondents (smokers) to the NZ International Tobacco Collaboration study saying they would quit if outlets reduced by 95%. We used the average of these two (19.4%) as the one-off increase in net cessation in the year of the policy implementation. The same magnitude reduction in initiation was included in the year of implementation and all subsequent years.
- Tobacco-free generation: in theory, initiation will reduce to zero. In practice, social supply is likely. The exact reduction in initiation is uncertain, so we specified that future initiation rates will be 10% of BAU with wide uncertainty, achieved 10 years after the policy is introduced.

Analyses

The smoking-vaping and PMSLT models were run in series, 2000 times using Monte Carlo simulation. For this paper, we produced the following outputs. First, deaths averted by time period. Second, health-adjusted life years (HALYs; 3% annual discount rate) gained from each intervention, both the total number and age-standardised (using Māori population 2020) per 1000 people. Third, we calculated the age-standardised all-cause mortality rate differences between Māori and non-Māori (by sex) for 45+ year old (by age in the future), under BAU and each intervention, and presented the percentage difference in the rate difference for each intervention compared to BAU.

Results

Achieving < 5% prevalence

The combined package achieves a profound and rapid reduction in smoking prevalence (Figure 1 and Supplementary Table S23). In 2022, the year before policy implementation, Maori age 20+ smoking prevalence is 31.8%, falling to 28.7% (95%UI: 28.0% to 29.2%) under BAU by 2025 (the year targeted to have smoking prevalence less than 5% by the A/NZ Parliament); under the combined package Māori smoking prevalence decreases to 7.6% (5.0% to 10.5%) in 2025 (females: 8.6%, 5.6% to 11.9%; males 6.6%, 4.4% to 9.1%). For non-Māori the smoking prevalence is 11.8% in 2022, falling to 10.7% (95%UI: 10.0% to 11.2%) in 2025 under BAU and decreasing to 2.8% (2.0% to 3.8%) under the combined package (females: 2.7%, 1.9% to 3.6%; males 3.0%, 2.1% to 4.0%). A combined package achieves the under 5% smoking prevalence target in 2026 and 2027 for Māori males and females, respectively.

Denicotinisaiton causes the majority of decreases in smoking. Retail outlet reduction has a strong impact in its year of implementation (due to a large cessation impact), but it then tracks largely as in BAU (as no ongoing increases in cessation are assumed, and reductions in initiation take years to accrue). Neither the retail reduction nor the tobacco-free generation strategies achieve less than 5% smoking prevalence by 2025 for any sex by ethnic group.

Deaths averted

Under the combined package, deaths up to 2040 were 8060 (95%UI: 6870 to 9360) less than under BAU, with 27% to 30% of these averted deaths among each of female Māori, female non-Māori and male non-Māori (Table 3).

HALYs gained

For the combined intervention compared to BAU, by sex and ethnic group, 28% to 30% of all HALYs gained by the combined package were among female Māori, female non-Māori and male non-Māori, with a lesser 14% among male Māori. For sexes and ethnic groups combined, and for the remainder of the lifespan of the population alive in 2020, there was an estimated 600,000 HALYs gained (95% UI: 515,000 to 698,000: bottom right of Table 4). The majority (90%) of these HALYs gained were after 2040.

The denicotinisation strategy alone achieves 97% of the HALYs of the combined package, retail outlet reduction alone 19% and the tobacco-free generation alone 12%. For the tobacco-free generation, the vast majority (98%) of HALYs gained over the lifespan of the population occurred after 2040.

Inequality impacts

Figure 2 shows the age-standardised per capita HALYs gains for Māori compared to non-Māori. For the combined package, Māori females gained 4.75 times as many HALYs per capita as non-Māori females, and Māori males gained 2.15 times as many as non-Māori males. The Māori:non-Māori ratio of per capita HALY gains was similar for other interventions, except it was higher for the tobacco-free generation (noting, though, that the absolute gains were less for this strategy – see Supplementary Table S24).

Māori 45+ years mortality rates in 2040 are 11.6% and 5.2% lower under the combined package than under BAU, for females and males respective. For non-Māori, these reductions are less at 2.8% and 2.3%, for females and males respectively. The impact of the combined endgame strategies on the Māori compared to non-Māori 'gap' (absolute difference) in mortality rates by 2040 is shown in Figure 3. The rate difference is 23.6% (95%UI: 20.5% to 27.2%) less for females for the combined package compared to BAU, and 9.6% (95%UI: 8.4% to 10.9%) less for males. The denicotinisation policy alone achieves most of this mortality rate inequality reduction, and the retail reduction strategy about a quarter of that for the combination strategy.

Discussion

In Aotearoa-New Zealand (A/NZ), a colonial country with a high smoking rates among the Indigenous Māori, we found that tobacco endgame strategies outlined in the December 2021 A/NZ Smokefree Plan [11], in particular denicotinisation of commercial tobacco, could have a profound positive impact on the health of Māori and notably reducing health inequity between Māori and non-Māori. For example, a combined package of denicotinisation plus media, 95% reduction in retail outlets and a tobacco-free generation would – we estimate – reduce the gap in 45+-year-old mortality rates by 22.9% for females by 2040 (compared to ongoing BAU), and by 9.6% for males. We doubt there is any other feasible health intervention that would reduce ethnic inequalities in mortality by as much.

Our results suggest mandating denicotinisation would have an immediate, marked and enduring impact on smoking prevalence in A/NZ. Importantly the impacts of this measure would make a significant contribution towards eliminating smoking prevalence inequities between Māori and non-Māori populations. Reducing retail access would have a lesser impact on overall prevalence and inequities and introducing a tobacco-free generation alone would take many years to take full effect with impact on smoking prevalence and then health gains. Nevertheless, the impacts of both of these measures are on par with tobacco tax increases,[25] and greater than interventions such as mass media and quit programmes alone.[26]

The profound impact of tobacco endgame strategies on ethnic health inequalities in A/NZ is due to higher smoking rates among Māori (especially females), but also because the smoking-related disease rates are higher among Māori (for both tobacco and non-tobacco-related reasons). Such patterning by indigeneity, ethnicity and socioeconomic position occurs in many other countries, suggesting tobacco endgame strategies will notably reduce health inequities in other countries – as well as improving the health of all citizen groups.

Tackling tobacco is not only a health issue; it has also a social and economic priority for Indigenous peoples.[27] Whilst not presented in this paper, modelling we conducted for the A/NZ Government to underpin the Action Plan estimated income gains of US$ 1.42 billion by 2040 (3% discount rate) due to the income gains occurring among those not dying prematurely or developing chronic disease, a fillip to the A/NZ productivity and GPD overall but also a pro-equity economic boost for Māori communities.

Colonisation is an underlying driver of ethnic inequalities in smoking behaviour. Māori engagement and leadership throughout the process of developing and subsequent implementation of A/NZs Action Plan has been essential to ensure the Plan itself is not a further expression of coloniality. Legislation for the actual implementation of the Plan is expected to happen during 2022 with different measures coming into force over the next few years.

Other than a temporary ban on tobacco sales in Bhutan, no country has implemented any of the endgame interventions proposed in the A/NZ Action Plan. This lack of evidence about the real-world impacts of endgame strategies means that modelling studies' assumptions about likely impact are based on theory, logic, expert views and simulation studies. It is therefore imperative that where endgame strategies are implemented, they are robustly evaluated to provide evidence to better inform decision-making – and improve modelled estimates such as in this current study. Second, such evaluations should include a thorough investigation of equity issues, including where applicable, the exploration of intended and unintended impacts on Indigenous peoples. Thirdly, the striking equity impacts of endgame interventions estimated in this study underline that future tobacco control modelling studies should explore impacts on inequities in smoking prevalence and smoking-related disease.

Strengths and limitations

We necessarily had to use expert judgement and estimates from scenario studies in specifying the impacts of endgame policies. We have attempted to be as transparent as possible, with the key assumptions outlined in Table 2. We specified generous uncertainty about most of these inputs, then used Monte Carlo simulations to generate uncertainty about our outputs of HALYs gained and mortality impacts. The uncertainty intervals about the HALYs, for example are non-overlapping between the denicotinisation and retail interventions, and with BAU, suggesting a strong degree of confidence in the likely magnitude of health gains and inequality impacts.

We used 2013-14 to 2019-20 health survey data to parametrise our smoking-vaping life history model. Since then, 2020-21 data has found a marked drop in smoking prevalence in all socio-demographic groups. If this drop is not just a statistical anomaly, then we may have over-estimated smoking rates in the base year and BAU in the future, therefore overestimating HALY gains and mortality rate reductions arising from endgame strategies. Second, we assumed all uptake occurred at age 20, and report smoking prevalence for 20+ year olds; had we used 15+ year olds as our denominator, the smoking prevalence results reported would have been lower.

A/NZ has a fairly liberal access to alternative nicotine products, such as vaping. This meant that in our modelling, some people quitting tobacco took up vaping for a while at least (Supplementary Table S24). The generalisability of our study to other countries will depend partly on their regulatory environment for vaping.

Homegrown tobacco grown for personal recreational use, and illicit supply, may provide some alternative tobacco source in A/NZ with denicotinisation or substantial reduction in retail access. However, neither is common in A/NZ, due to a non-ideal physical environment in most of A/NZ for growing of tobacco for personal use, and tight border security in an island nation with no land borders.

We have highlighted the importance of Māori and Indigenous engagement in the development and implementation of A/NZs Action Plan. The Plan also draws attention to the need for research and evaluation to provide an accountability mechanism to Māori. In this paper we attempted to uphold Indigenous Data Sovereignty principles, including Māori and other First peoples contributors (AW, RM and RL), providing data analysed against Indigenous population norms and including Indigenous interpretations. But more should be done in the future to engage Maori governance of research alongside the implementation of the Action Plan, facilitating Māori researchers undertaking that research where practicable, and prioritizing dissemination of findings to Māori communities first.

Conclusion

Many countries have Indigenous, ethnic and socio-economic inequalities in tobacco use. This modelling study suggests that tobacco endgame strategies could have major impacts both on overall health status, and on reducing inequalities in health.

Contributorship

Our team brings Māori lived experience (AW), Indigenous lived experience (RM, RL), and experience in research on tobacco inequalities (AW, RM, CG, RL, RE, NW, TB).

DAO, JS, NW and TB led the conceptualisation of the computer simulation modelling with data and other input specified by TW, HA and SRM. DAO and TW led the analyses and production of outputs, tables and figures. All authors interpreted the data. AW, RM and RL initiated the drafting of the Introduction and Discussion, TB led the Methods and Results, and DAO led the Appendix. All authors revised the draft manuscript critically for important intellectual content.

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- funded the initial analyses
- did not contribute to drafting this paper
- did contribute to conceptualization of the interventions, as they are integral to the NZ Action Plan

- did provide NZ Health Survey data to parametrise the smoking-vaping life history Markov model.

Declarations of Interest

Nil.

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Nil.

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Tables and Figures

Table 1: Baseline and business-as-usual parameters

Parameter	Data Source	Trend, Uncertainty, and Scenario Analyses
Demography		
Population	Statistics New Zealand (SNZ) population estimates for 2018 by sex, age-group, and ethnicity.	Uncertainty: nil
BAU – epidemiological parameters		
All-cause mortality rates (ACMR)	SNZ mortality rates by sex, age, and ethnicity for 2020	Trends in ACMR were estimated using GHDx data (IMME). The annual percentage change in the age-standardised all-cause mortality rates from 1990 to 2019 was -1.9% for sexes combined. Retaining the original BODE3 model assumption of a 0.5 percent point greater APC for Māori (due to long run trends of closing ethnic inequalities in mortality), we arrived at APC's for ACMR from 2020 to 2035 of: Māori = -2.0%; non-Māori =-1.5%. They were uniform by age. No trends applied beyond 2035. Uncertainty: nil.
All-cause morbidity rates	NZ Burden of Disease Study [20]	Data on years of life lived with disability (YLD) were obtained from the NZBDS for each sex and age group in 2016 and divided by the population in each sex by age by ethnic group to generate morbidity rates. No time trend was allowed.
Disease specific incidence, prevalence, and case-fatality rates	NZ Burden of Disease Study [20]	For each tobacco-related disease, coherent sets (by sex, age, and ethnicity) of incidence rates, prevalence, case-fatality rates (CFR), and remission rates (zero for non-cancers, the complement of the CFR for cancers to give the expected 5-y relative survival) were estimated using DISMOD II. Cancer incidence and CFR annual percentage change (APC) trends using Poisson regression historic trends of incidence and case-fatality rates of diseases. The APCs included as inputs to the PMSLT model out to year 2035 and held constant beyond (future prevalence changes dynamically with model). It was assumed that the APCs were constant by ethnicity. Uncertainty: starting in 2020, rates all +/- 5% standard deviation (SD), correlations 1.0 between four sex by ethnic group categories for all diseases. APC all +/- 0.5% SD normal, correlations 1.0 between four sex by ethnic groups for all diseases.
Disease specific morbidity	NZ Burden of Disease Study [20]	The sex and age specific disability rates were calculated as disease's YLD obtained divided by the prevalent cases.

Parameter	Data Source	Trend, Uncertainty, and Scenario Analyses
		The same disability rate was assumed by ethnicity (i.e., those with disease are assumed to have same severity distribution across ethnicity). Uncertainty: +/- 5% SD (beta distribution)
Tobacco smoking and vaping		
Smoking (daily)	NZ Health Survey	Logistic regression of NZ Health Survey data for years 2011 to 2019 was undertaken to 'predict' the prevalence of daily smoking (at least one cigarette per day) for years 2020 to 2040. This 'prediction file' was then re-analysed from a sex by ethnicity by five-year age group perspective (i.e., 72 separate sex by age by ethnicity cohorts) to generate future BAU smoking prevalence – and a yearly (cohort aging) rate of decline – that was then used in the exposure model.
Vaping (daily e-cigarette use)	NZ Health Survey	Same as above for smoking, but for 'vaping' at least daily.
Association of smoking and vaping with disease incidence rates		
Smoking-disease incidence rate ratios	Relative risks of disease incidence for the association of current (or ex-smoker) with never smoker were sourced from NZ linked census-cancer[28] and census-mortality[29] (censuses include smoking question) and CPS II data for respiratory diseases.[30] Attenuation over time since quitting for ex-smokers was modelled using equations and coefficients from Hoogenveen et al.[31]	Standard errors of regression coefficients as described in Appendix C

Table 2: Intervention input parameter table

Parameter	Description
Low nicotine	
NS→ CS (age 20 only) NS→ DU (age 20 only)	10% (SD 5%) of BAU initiation at age 20 by five years after implementation (X= Beta (3.6, 32.4), median 9.3%, 95% UI 2.6% to 21.5%.). Implemented as $X^{\wedge(t/5)}$ scalar applied to the BAU initiation rates in years t (1 to 5) after introduction of the policy, then held at X% thereafter.
CS→ FSFV CS→ FSCV DU→ FSFV DU→ FSCV	Using an expert knowledge elicitation (see Appendix D), smoking prevalence (i.e. X=prevalence in states CS and DU) with mean 15.2% (SD 7.84%, X=Beta (3.19, 17.78), median 14.1%, 95%UI: 3.7% to 32.9%) of BAU smoking prevalence five years after low nicotine policy implementation, due to quitting or switching to vaping (i.e. disregarding initiation impacts that will additionally impact prevalence among 20-24 year olds in first five years of the model). . Implementation was as $X^{\wedge(t/5)}$ scalar applied to BAU CS and DU prevalence, with the intervention transition probability was BAU [for that transition in that year for each sex by ethnic by age group] + (1-BAU)×0.5×$X^{\wedge t/5}$, where *t* is the 1 to 5 years after intervention. For the sixth and subsequent years, the transition probabilities were twice those in BAU (due to an ongoing higher NCR, given non-addictive levels of nicotine in tobacco).
NS→NSCV	No change.
Low nicotine plus Mass media	
NS→ CS (age 20 only)	As above for low nicotine.
NS→ DU (age 20 only)	As above for low nicotine.
NS→ NSCV (age 20 only)	No change.
CS→ FSFV CS→ FSCV DU→ FSFV DU→ FSCV	As above for low nicotine from year 1 to 5 + twice the absolute contribution of the routine media/Quitline campaign to background net cessation (i.e. 1.055% * 2)[26] Subsequent years: transition to quitting or vaping were twice those in BAU
Retail outlet restriction to about 300 outlets (about 5% of current outlets; assumed supply of e-cigarettes reduces commensurately) †	
NS→ CS	As per the increase in cessation probabilities (CS→FSFV, etc, below) , we reduced the initiation rate by X= Beta (23.4, 97.2), median 19.2%, 95%UI: 12.9% to 26.9%. Applies in 2023 onwards (as youth contemplating initiating in the future confront lesser retail availability as well).

Parameter	Description
NS→ DU	As above for NS → CS.
CS→ FSFV CS→ FSCV DU→ FSFV DU→ FSCV	As a low estimate of one-off quitting, we used that from studies modelling reducing retail outlets in terms of increased travel costs [32]: a reduction in the prevalence of 15.6% for Māori, and 16.0% for non-Māori – or 15.8% overall. As a high estimate, we used that from the NZ ITC study where – in response to a question whether they would quit in response to a 95% reduction in retail outlets - 23.0% said they would quit (half quitting → FSFV, half switching to FSCV).[33] Placing the mean at 19.4% (average of above 15.8% and 23%) and using 15.8% and 23% as one SD either side of the mean (SD = 3.6%), we parameterised the one-off increase in smoking net cessation as X=Beta (23.4, 97.2), median 19.2%, 95%UI: 12.9% to 26.9%. Note this increase was on top of BAU transition probabilities, and halved over CS→FSFV and CS→FSCV, and halved over DU→FSFV and DU→FSCV. E.g. if the CS→FSFV was 5%, the intervention CS→FSFV transition probability was 5% + (1-5%)×0.5×X%. This effect was in the year of intervention only– in years after the retail outlet restriction, the transition probabilities out of CS and DU reverted to BAU.
NS→NSCV	Unchanged
Tobacco-free generation	
Smoking initiation rate (NS→ CS; occurs only at age 20)	For two reasons, a tobacco-free generation proposal will not immediately achieve zero uptake at age 20; 1) our model for parsimony assumes all uptake at age 20, but the minimum legal age of purchasing is 18 years; 2) social supply will allow some young people to keep initiating. We therefore assumed that initiation at age 20 in our model (essentially an average of all initiation by [say] age 25) will asymptote to a mean of X=10% (SD 5%) of BAU in 10 years (Beta (3.6, 32.4), median 9.3%, 95%UI: 2.6% to 21.5%), with the scalar of BAU initiation rate of $X^{\wedge(t/10)}$ for t = 1 to 10 years after the tobacco-free generation policy is implemented, then X of BAU initiation thereafter.
NS→ DU	As above for NS→CS.
NS→ NSCV	Unchanged†

Parameter	Description
Combined: Denicotinisation + retail + tobacco-free	
NS→ CS (age 20 only)	Cumulative impact. If the % reduction in initiation in year t for denicotinisation, retail and tobacco-free was A%, B%, and C%, then the reduction in the combined intervention was 1 – (1-A)(1-B)(1-C).
NS→ DU (age 20 only)	As above for NS→CS.
CS→ FSFV CS→ FSCV DU→ FSFV DU→ FSCV	Cumulative impact. If the % increase in quitting or switching in year t for denicotinisation and retail was A% and B%, then the increase in the combined intervention was 1 – (1-A)(1-B).
NS→ NSCV	Unchanged.

NS=never smoker; CS=current smoker (but not a dual user); DU=dual user; NSCV=never smoker, current vaper; FSFV=former smoker and/or former vaper; FSCV=former smoker current vaper.

†If the availability of alternative nicotine delivery systems (ENDS; e.g. e-cigarettes) does not reduce commensurately with these policy interventions, one would expect larger switched to ANDS which would reduce smoking prevalence further (but increase DU, FSCV and possibly NSCV state prevalence). We do not model this explicitly, but consider it in the Discussion.

Table 3: Deaths averted† during 2020-30 and 2031-40, in Aotearoa New Zealand by strategy

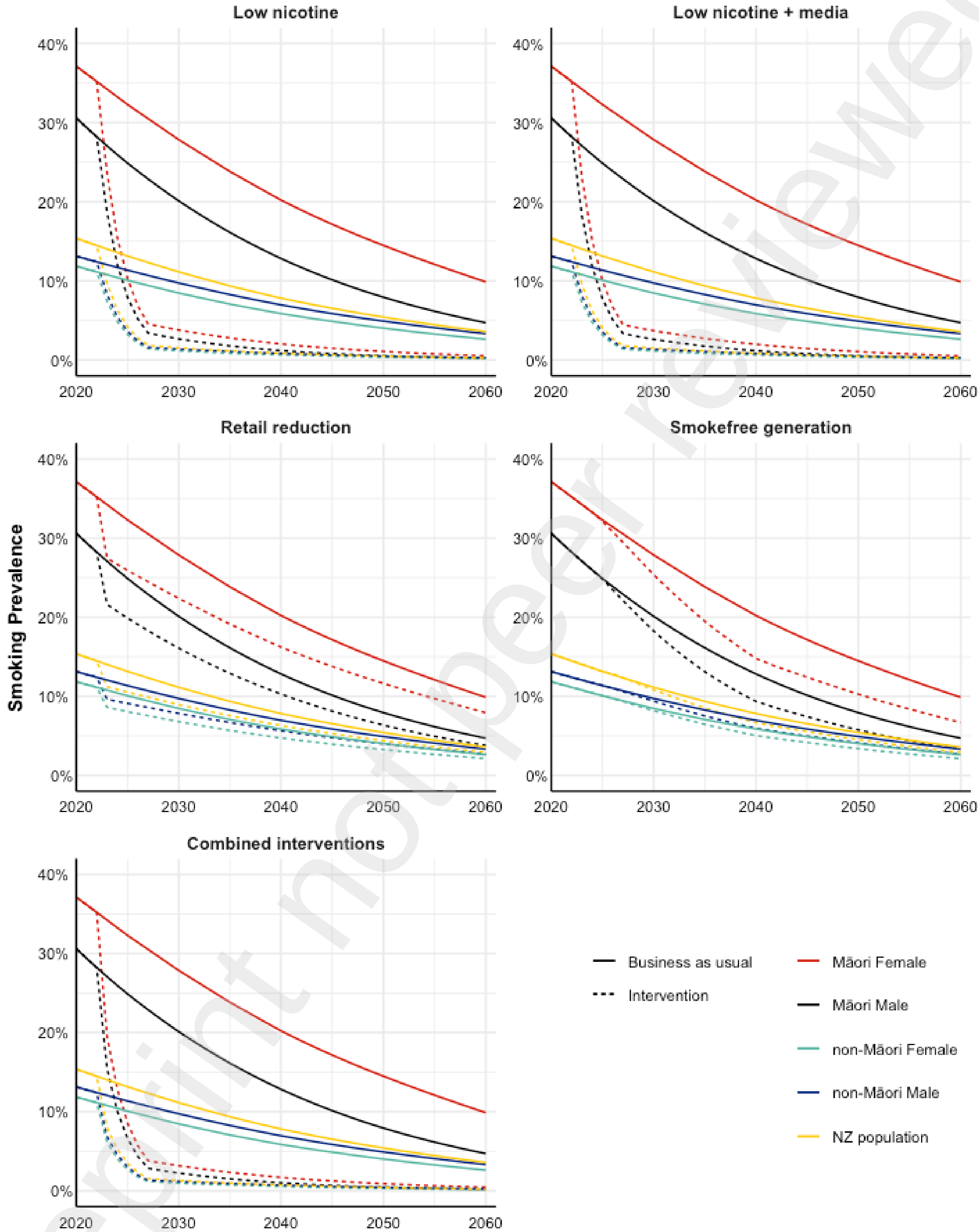
Population	Year	Denicotinisation		Denicotinisation + media		Retail reduction		Tobacco-free generation		Combined interventions	
		Est	95%UI	Est	95%UI	Est	95%UI	Est	95%UI	Est	95%UI
Female Māori (n= 428,948 in 2020)	2020 to 2030	260	(192 to 332)	263	(201 to 338)	88	(66 to 114)	0.55	(0.45 to 0.68)	289	(231 to 354)
	2031 to 2040	1,800	(1540 to 2090)	1,810	(1540 to 2110)	446	(332 to 587)	13	(11 to 15)	1,880	(1630 to 2170)
	2020 to 2040	2,060	(1740 to 2410)	2,080	(1740 to 2440)	535	(399 to 701)	14	(12 to 16)	2,170	(1860 to 2520)
Female Non-Māori (n=2,132,141 in 2020)	2020 to 2030	279	(209 to 356)	283	(215 to 362)	98	(75 to 125)	0.44	(0.36 to 0.53)	313	(249 to 383)
	2031 to 2040	1,950	(1660 to 2290)	1,970	(1650 to 2310)	506	(383 to 654)	8.4	(7.1 to 9.7)	2,050	(1740 to 2390)
	2020 to 2040	2,230	(1880 to 2630)	2,250	(1880 to 2670)	604	(458 to 776)	8.8	(7.5 to 10)	2,360	(2000 to 2760)
Male Māori (n= 425,740 in 2020)	2020 to 2030	139	(104 to 178)	141	(107 to 181)	49	(38 to 63)	0.01	(0 to 0.01)	157	(124 to 191)
	2031 to 2040	871	(749 to 1000)	877	(753 to 1020)	225	(170 to 289)	3.6	(3.1 to 4.2)	915	(794 to 1050)
	2020 to 2040	1,010	(857 to 1180)	1,020	(864 to 1190)	274	(208 to 352)	3.6	(3.1 to 4.2)	1,070	(923 to 1240)
Male Non-Māori (n= 2,099,493 in 2020)	2020 to 2030	325	(247 to 409)	330	(255 to 417)	114	(89 to 142)	0.18	(0.15 to 0.23)	365	(292 to 443)
	2031 to 2040	1,980	(1650 to 2350)	2,000	(1660 to 2370)	510	(388 to 652)	3.6	(3 to 4.3)	2,080	(1750 to 2450)
	2020 to 2040	2,300	(1910 to 2750)	2,330	(1920 to 2770)	625	(479 to 793)	3.8	(3.2 to 4.5)	2,440	(2050 to 2880)
All (n= 5,086,322 in 2020)	2020 to 2030	1,000	(757 to 1270)	1,020	(779 to 1300)	349	(271 to 441)	1.2	(0.98 to 1.4)	1,120	(897 to 1370)
	2031 to 2040	6,600	(5630 to 7690)	6,660	(5640 to 7780)	1,690	(1280 to 2170)	29	(25 to 33)	6,940	(5930 to 8020)
	2020 to 2040	7,610	(6440 to 8920)	7,680	(6460 to 9010)	2,040	(1550 to 2610)	30	(26 to 34)	8,060	(6870 to 9360)

†Deaths averted over the period, i.e., total deaths over each ten-year period in BAU minus intervention.

Table 4: Health gain (in HALYs gained) for people alive in 2020 (base-year, N = 5,086,322) in Aotearoa New Zealand by the modelled policies, by timeline into the future (3% discount rate)

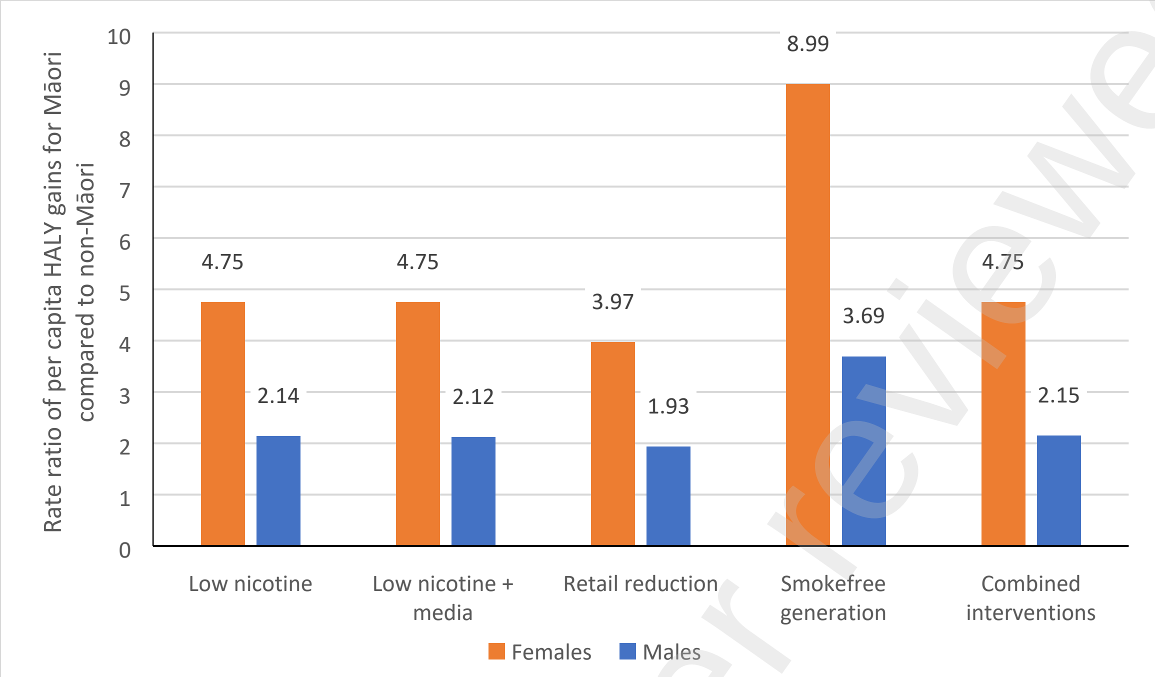
Population	Year	Denicotinisation		Denicotinisation + media		Retail reduction		Tobacco-free generation		Combined interventions	
		Estimate	95% UI	Estimate	95% UI	Estimate	95% UI	Estimate	95% UI	Estimate	95% UI
Female Māori	2020 to 2030	945	(665 to 1,250)	963	(700 to 1,270)	339	(255 to 436)	23	(19 to 27)	1080	(845 to 1,340)
	2031 to 2040	10700	(8,910 to 12,400)	10700	(9,110 to 12,500)	2830	(2,130 to 3,670)	318	(269 to 378)	11400	(9,870 to 13,000)
	2041 to 2131	155000	(137,000 to 174,000)	155000	(137,000 to 175,000)	25400	(19,100 to 33,100)	31400	(23,700 to 36,400)	160000	(143,000 to 179,000)
	All	166000	(147,000 to 187,000)	167000	(147,000 to 189,000)	28600	(21,500 to 37,200)	31800	(24,000 to 36,800)	172000	(153,000 to 193,000)
Female Non-Māori	2020 to 2030	1440	(1,040 to 1,880)	1470	(1,100 to 1,910)	528	(409 to 673)	22	(18 to 27)	1650	(1,300 to 2,030)
	2031 to 2040	14800	(12,300 to 17,300)	14900	(12,600 to 17,500)	4030	(3,100 to 5,200)	329	(274 to 398)	15800	(13,600 to 18,200)
	2041 to 2131	146000	(123,000 to 174,000)	147000	(123,000 to 175,000)	28900	(21,700 to 38,100)	16000	(12,000 to 19,900)	151000	(127,000 to 179,000)
	All	162000	(137,000 to 192,000)	163000	(137,000 to 194,000)	33400	(25,300 to 44,000)	16400	(12,300 to 20,300)	168000	(142,000 to 199,000)
Male Māori	2020 to 2030	590	(424 to 773)	602	(447 to 787)	216	(166 to 276)	16	(14 to 20)	680	(535 to 838)
	2031 to 2040	6120	(5,140 to 7,110)	6160	(5,240 to 7,200)	1660	(1,270 to 2,130)	227	(190 to 271)	6550	(5,670 to 7,490)
	2041 to 2131	72100	(62,000 to 83,800)	72400	(62,300 to 84,500)	12800	(9,750 to 16,600)	13300	(10,200 to 16,300)	74500	(64,400 to 86,500)
	All	78900	(67,900 to 91,200)	79200	(68,200 to 92,100)	14600	(11,200 to 19,000)	13500	(10,400 to 16,500)	81700	(70,900 to 94,400)
Male Non-Māori	2020 to 2030	1590	(1,180 to 2,040)	1630	(1,240 to 2,100)	586	(461 to 729)	24	(19 to 28)	1830	(1,470 to 2,240)
	2031 to 2040	15900	(13,200 to 18,700)	16000	(13,400 to 18,900)	4320	(3,360 to 5,500)	340	(283 to 412)	17000	(14,500 to 19,700)
	2041 to 2131	154000	(125,000 to 189,000)	155000	(125,000 to 190,000)	30200	(22,600 to 39,900)	17000	(12,300 to 22,000)	160000	(129,000 to 194,000)
	All	171000	(140,000 to 210,000)	173000	(141,000 to 210,000)	35100	(26,400 to 46,200)	17300	(12,600 to 22,400)	178000	(146,000 to 215,000)
All population	2020 to 2030	4570	(3,310 to 5,930)	4650	(3,500 to 6,060)	1670	(1,300 to 2,110)	85	(70 to 101)	5250	(4,170 to 6,440)
	2031 to 2040	47400	(39,800 to 55,300)	47800	(40,500 to 56,000)	12900	(9,900 to 16,500)	1210	(1,020 to 1,460)	50700	(43,700 to 58,300)
	2041 to 2131	527000	(451,000 to 618,000)	529000	(452,000 to 621,000)	97100	(73,800 to 128,000)	77600	(58,700 to 93,700)	545000	(466,000 to 636,000)
	All	579000	(495,000 to 677,000)	582000	(497,000 to 680,000)	112000	(85,100 to 146,000)	78900	(59,800 to 95,200)	600000	(515,000 to 698,000)

Figure 1. Smoking prevalence (daily, 20+ year population) in Aotearoa New Zealand under business-as-usual and interventions



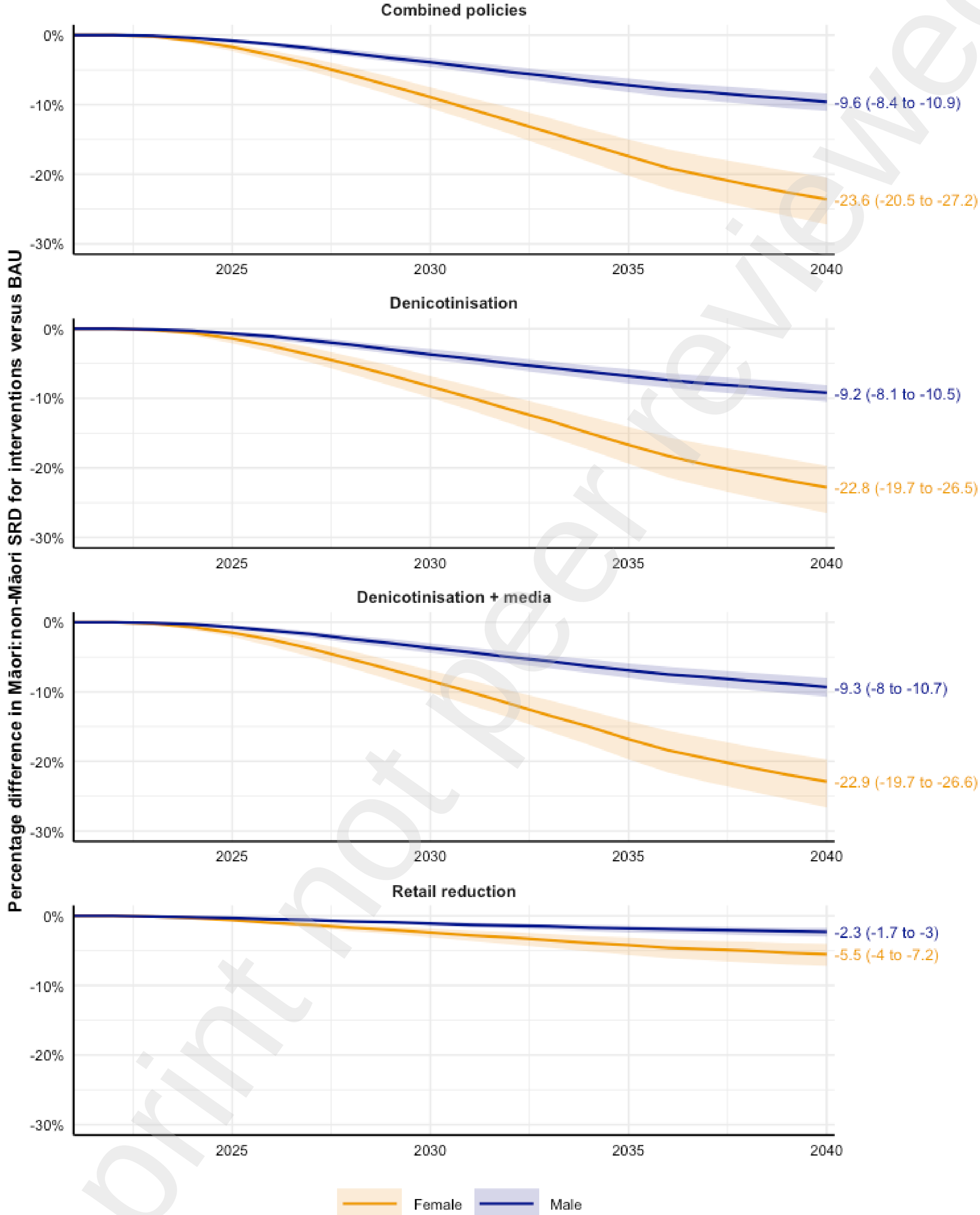
Note: Prevalences are not age-standardised and are calculated for the projected age-structure of each sex by ethnic group in future years.

Figure 2: Ratios of per capita HALY gains over the remainder of the 2020 Aotearoa-New Zealand population's lifespan, for Māori compared to non-Māori



Calculated using cohorts defined by age in 2020, age standardised using the 2020 Māori population.

Figure 3: Projected percentage changes in age-standardised all-cause mortality rate differences (≥ 45 years) between Māori and non-Māori, for endgame strategies † compared to BAU



SRD: Standardised rate difference. Rates are standardised to the Māori population

† We do not show the tobacco-free generation as there is no change in 45 plus year old mortality rates in this timeline.