Tobacco endgame intervention impacts on health gains and Māori:non-Māori health inequity: a simulation study of the Aotearoa/New Zealand Tobacco Action Plan

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ABSTRACT

Background The Aotearoa/New Zealand Government is aiming to end the tobacco epidemic and markedly reduce Māori:non-Māori health inequalities by legislating: (1) denicotinisation of retail tobacco, (2) 95% reduction in retail outlets and (c) a tobacco free-generation whereby people born after 2005 are unable to legally purchase tobacco. This paper estimates future smoking prevalence, mortality inequality and health-adjusted life year (HALY) impacts of these strategies.

Methods We used a Markov model to estimate future yearly smoking and vaping prevalence, linked to a proportional multistate life table model to estimate future mortality and HALYs.

Results The combined package of strategies (plus media promotion) reduced adult smoking prevalence from 31.8% in 2022 to 7.3% in 2025 for Māori, and 11.8% to 2.7% for non-Māori. The 5% smoking prevalence target was forecast to be achieved in 2026 and 2027 for Māori males and females, respectively. The HALY gains for the combined package over the population's remaining lifespan were estimated to be 594 000 (95% uncertainty interval (UI): 443 000 to 738 000; 3% discount rate). Denicotinisation alone achieved 97% of these HALYs, the retail strategy 19% and tobacco-free generation 12%.
By 2040, the combined package was forcat to reduce the gap in Māori:non-Māori all-cause mortality rates for people 45+ years old by 22.9% (95% UI: 19.9% to 26.2%) for females and 9.6% (8.4% to 11.0%) for males.

Conclusion A tobacco endgame strategy, especially denicotinisation, could deliver large health benefits and dramatically reduce health inequities between Māori and non-Māori in Aotearoa/New Zealand.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Modelling of health gains and health inequality reductions for some tobacco endgame strategies has been undertaken internationally, and specifically in Aotearoa, such as tobacco-free generation policy, substantial reductions in the number of tobacco outlets, including a sinking lid that gradually phased out all tobacco supply between 2011 and 2025 and restricting tobacco sales to pharmacies only with brief cessation advice provided to consumers. All modelling suggested that these interventions improved equity, of varying magnitude, in either smoking prevalence or health gain for Māori compared with non-Māori.

⇒ Endgame modelling of denicotinisation has not been undertaken, alone or in combination with other interventions. The interplay of tobacco smoking and vaping has not been explicitly included in endgame modelling. The package of endgame strategies in the Aotearoa/New Zealand Government's Smokefree Action Plan (December 2021) has not been modelled.

INTRODUCTION

Despite unequivocal evidence about the harm caused by commercial tobacco, it continues to be a leading cause of avoidable morbidity and mortality.[1] Smoking prevalence in high-income countries with colonial histories has steadily decreased, but prevalence among Indigenous peoples is often substantially higher[2] and is a significant contributor to health inequities.[3]

Indigenous peoples' experiences of colonisation include imposition of alien societal institutions, appropriation of economic resources and exposure to racism. Referred to as 'basic causes',[4 5] these affect access to social determinants of health (eg, income, housing) and, via health behaviours such as smoking rates, ultimately leading 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.[2 6 7]

In 2021–2022, 19.9% of Māori (the Indigenous peoples of Aotearoa/New Zealand (A/NZ)), 18.2% of Pacifica, 2.6% of Asian and 7.2% of European/Other aged 15 years and older smoked at least daily.[8] Over the last 2 years, the decline in smoking prevalence accelerated from 11.9% (95% CI 11.1% to 12.7%) for all ethnic groups combined in 2019–2020 to 8.0% (95% CI 7.0% to 9.0%) in 2021/2022. Over the same period, daily vaping prevalence increased from 3.5% (95% CI 3.0% to 4.1%) in 2019–2020 to 8.3% (95% CI 7.1% to 9.7%) in 2021–2022. Vaping prevalence was highest for people 18–28 years old (22.9%)

WHAT THIS STUDY ADDS

⇒ The government's package (denicotinisation of retail tobacco, 95% reduction in the number of tobacco retail outlets and a tobacco-free generation), if implemented in 2023, is forecast to achieve less than 5% smoking prevalence by 2025 for non-Māori and by 2027 for Māori.

⇒ Denicotinisation is estimated to achieve the majority of the health gains.

⇒ A 95% retail outlet reduction and a tobacco-free generation, on their own, are unlikely to achieve a 5% smoking prevalence for any sex by ethnic groups until at least 2040.

⇒ The combined package, compared with business as usual, is estimated to reduce the Māori:non-Māori gap in all-cause mortality of those aged 45+ years old in 2040 by 22.9% (95% uncertainty interval (UI) 19.9% to 26.2%) for females and 9.6% (95% UI: 8.4% to 11.0%) for males.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ 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, modelling how the Aotearoa/New Zealand Government's endgame legislation is implemented and the outcomes it might achieve will provide important empirical evidence to inform policy action in other countries.

and among Māori (2.09 times non-Māori). The reasons for the recent acceleration of decline in tobacco smoking, and increase in vaping, may be due to a mix of: ongoing tobacco control efforts; relative ease of access to vaping products and economic pressures that favour lower-cost vaping over smoking; impacts of the pandemic; and possibly anticipatory changes due to the policies modelled in this paper that have received much media coverage.

Similar to other high-income countries, A/NZ's tobacco control programme includes: restricting the promotion of tobacco products, providing cessation support, mass media campaigns, regular increases in excise tax and smoke-free areas.[9] Many of these measures rely on individual capacity and access to the resources needed to quit cigarettes. These resources are inequitably distributed across the A/NZ population, likely explaining a failure of A/NZ's tobacco control programme to address smoking disparities in the past. Concern about the slow progress in reducing smoking prevalence among Māori 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 smoke-free country by 2025[10] (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,[11] but actual tobacco control policy remained relatively unchanged. The 2010s coincided with the proliferation of alternative nicotine delivery devices (e-cigarettes in particular) and introduced a discourse about 'harm minimisation' to the endgame debate.[12] 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.[13] 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 (eg, ≤0.4 mg nicotine/cigarette),[14] 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 (eg, 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.[15] A challenge of these types of measures is that they would act against Indigenous aspirations of empowerment and self-determination[16] 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 a growing interest in tobacco endgame goals and strategies. Scotland, for example, has included a strong focus on equity within their endgame goals and strategies,[17] but, other than in A/NZ, a focus on Indigenous health inequities has not been a key objective of endgame strategies. To date, the implementation of endgame interventions has been minimal and, consequently, the evidence base of their potential effects is weak.[18] 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 inequities) 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 inequities?

We used simulation modelling to calculate these estimates, using a range of data inputs from trial evidence (eg, for very low nicotine cigarettes) to observational evidence (eg, people who smoke responses to what they would do in the face of policies proposed) to expert knowledge elicitation when required. Forecasting the future is uncertain. Accordingly, all input parameters have uncertainty related to them that the reader can inspect, all outputs incorporate uncertainty due to the propagated input parameter uncertainty in Monte Carlo simulation and we tease apart which input parameter drives most of the output uncertainty. A key principle of this study is that even if as a research community we do not have ideal data, decision-makers and society need the best estimates we can produce, with appropriate depiction and caveats about inevitable uncertainty.

METHODS

We used an existing tobacco simulation model[19–21] (rated as best of 25 tobacco models globally[22]) and expanded its capabilities to create a new model called Scalable Health Intervention Evaluation (SHINE) tobacco, which includes 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 (online supplemental figure S1 and table S1): never smoker (NS), current smoker (CS), never 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 is 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 years 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 quitting (see below).

To specify the transition probabilities under BAU, we first estimated future daily smoking (and vaping) rates by extrapolating trends in the 2013–2014 to 2019–2020 NZ Health Survey data, using a two-step regression approach: (1) a best fit regression model to historical data; and (2) 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 elected to not incorporate 2020–2021 and 2021–2022 data in the calibration for three reasons: (a) the exceptional circumstances of the COVID-19 pandemic and the likely impact on smoking; (b) the accelerating decline in smoking prevalence in the last 2 years may partially reflect anticipatory effects of people who smoke realising the endgame policy package is imminent; (c) if incorporating the last 2 years of data, it is unclear whether to only use the last 3 years of data to forecast future smoking prevalence (which is too little data for forecasting), or some average of the trend from 2013 to 2014 to 2021–2022.

Table 1 Baseline and business-as-usual (BAU) 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 (ACMRs)	SNZ mortality rates by sex, age and ethnicity for 2020	Trends in ACMR were estimated using data from the GHDx database IHME. 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% point greater APC for Māori (due to long run trends of closing ethnic inequalities in mortality), we arrived at APCs 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 (NZBDS)[25]	Data on years of life lived with disability (YLD) were obtained from the NZBDS for each sex and age group in 2016[25] 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 (CFRs)	NZBDS[25]	For each tobacco-related disease, coherent sets (by sex, age and ethnicity) of incidence rates, prevalence, CFRs and remission rates (zero for non-cancers, the complement of the CFR for cancers to give the expected 5-year relative survival) were estimated using the software DisMod II. Cancer incidence and CFR APC trend using Poisson regression historical trends of incidence and CFRs 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% 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	NZBDS[25]	The sex and age-specific disability rates were calculated as disease's YLD obtained divided by the prevalent cases. The same disability rate was assumed by ethnicity (ie, 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 2011–2019 was undertaken to 'predict' the prevalence of daily smoking (at least one cigarette per day) for years 2020–2040. This 'prediction file' was then reanalysed from a sex by ethnicity by 5-year age group perspective (ie, 72 separate sex by age by ethnicity cohorts) to generate future BAU smoking prevalence—and a yearly (cohort ageing) 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[33] and census mortality[34] (censuses include smoking question) and data from the Cancer Prevention Study II for respiratory diseases.[35] Attenuation over time since quitting for ex-smokers was modelled using equations and coefficients from Hoogenveen *et al*.[36]	Standard errors of regression coefficients as described in online supplemental appendix C and tables S20 and S21.

APC, annual percentage change; BODE3, Burden of Disease Epidemiology, Equity and Cost-Effectiveness; GHDx, Global Health Data Exchange; IHME, Institute of Health Metrics and Evaluation; PMSLT, proportional multistate life table.

Table 2 Intervention input parameter table

Parameter	Description
Denicotinisation	
NS→CS (age 20 only) NS→DU (age 20 only)	90% (SD 5%) of BAU initiation at age 20 by 5 years after implementation (X=beta (32.4, 3.6), median 90.7%, 95% UI: 78.5% to 97.4%.). Implemented as $1-(1-X)^{(t/5)}$ scalar applied to the BAU initiation rates in years t (1–5) after introduction of the policy, then held at 1–X% thereafter.
CS→FSFV CS→FSCV DU→FSFV DU→FSCV	Using an expert knowledge elicitation (see online supplemental appendix D), the reduction in smoking prevalence 5 years after the low nicotine policy compared with BAU in 5 years, due to quitting or switching to vaping, was mean 84.4% (SD 7.84%, X=beta (17.78, 3.19), median 85.9%, 95% UI: 67.1% to 96.3%). Implementation was as $1-(1-X)^{(t/5)}$ scalar applied to BAU CS and DU prevalence, where t is the 1–5 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.
Denicotinisation 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 added to background net cessation (ie, 1.055%×2=2.1%)[30] Subsequent years: transition to quitting or vaping was 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).
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[37]: 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 New Zealand - International Tobacco Control 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).[38] 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% (ie, percentage point increase), 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. For example, 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 $X^{(t/10)}$ for t=1–10 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.*
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, media and retail was A% and B%, then the increase in the combined intervention was 1–(1 – A)(1–B)(1 –C).
NS→NSCV	Unchanged.

*If the availability of alternative nicotine delivery systems (ANDS, for example, 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 section.
BAU, business as usual; CS, current smoker (but not a dual user); DU, dual user; FSCV, former smoker current vaper; FSFV, former smoker and/or former vaper; NCR, net cessation rate; NS, never smoker; NSCV, never smoker current vaper; NZ, New Zealand; UI, uncertainty interval.

We then calculated annual transition probabilities to achieve these projections, starting with transition probabilities between the seven states from the UK as reported by Doan *et al*[23] (online supplemental 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 years), and interpolated other age cohorts.

Proportional multistate life table 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), with detailed description provided elsewhere.[24] Briefly, the PMSLT is composed of a main cohort life table, 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). Thus, for the youngest people, we are estimating HALYs as far out as 2131; however, we focus on the next 20 years in much of the results. In parallel, proportions of the cohort also reside in 16 subsidiary tobacco-related disease life tables according to prevalence at baseline (ie, start of model), and in future years based on BAU disease-specific incidence, case fatality and remission rates. Within each disease life table, morbidity estimates (ie, disability rates from the NZ Burden of Disease Study[25]) are attached to prevalent cases. Tobacco-related diseases included in the model are: coronary heart disease, stroke, chronic obstructive pulmonary disease, lower respiratory tract infection and 12 cancers (lung,

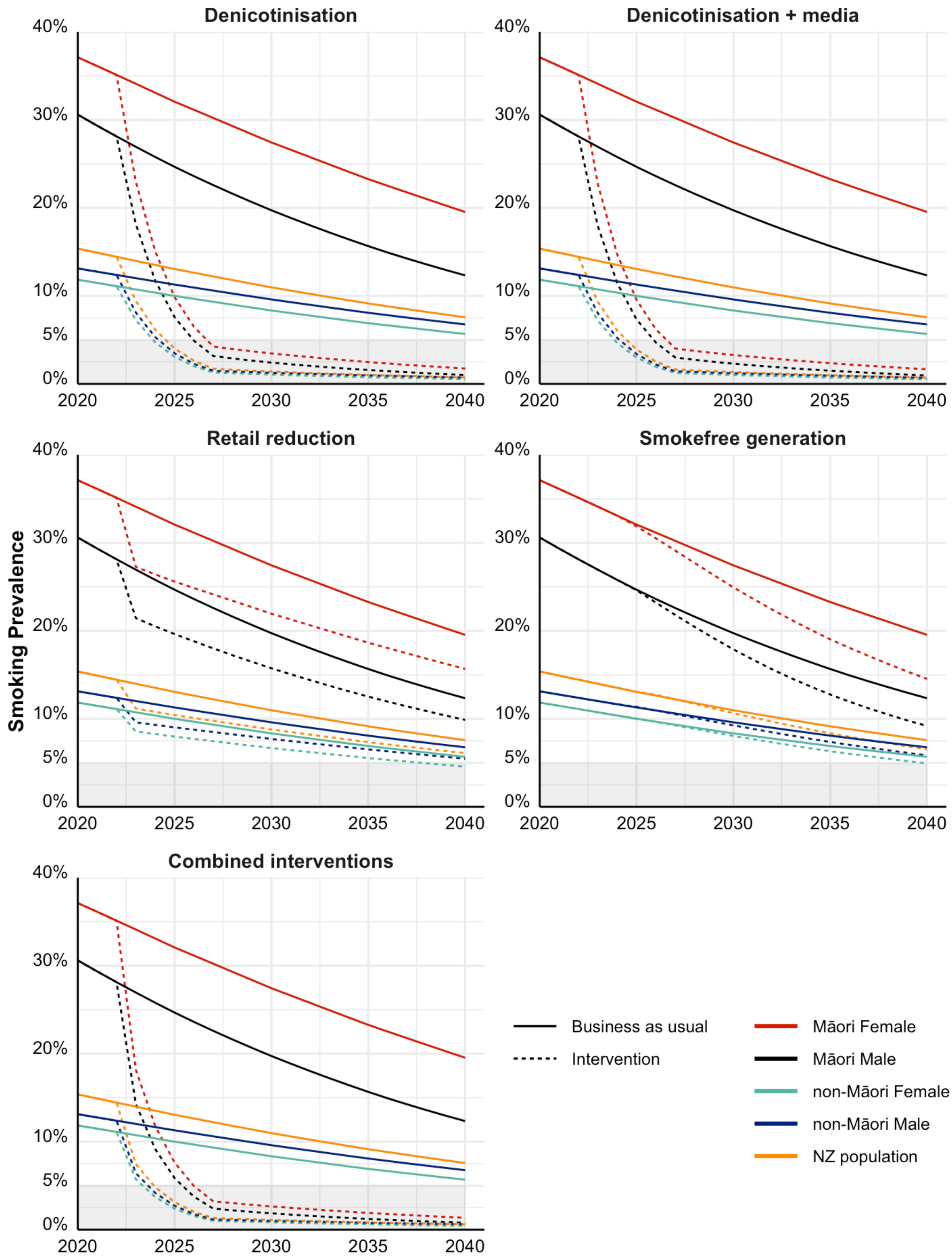

Figure 1 Smoking prevalence (daily, 20+ year population) in Aotearoa New Zealand (NZ) under business as usual and interventions. Prevalences are not age standardised and are calculated for the projected age structure of each sex by ethnic group in future years.

oesophageal, stomach, liver, head and neck, pancreas, cervical, bladder, kidney, endometrial, melanoma and thyroid).

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

Table 3 Deaths averted* during 2020–2030 and 2031–2040, in Aotearoa New Zealand by strategy

Population	Year	Denicotinisation		Denicotinisation+media		Retail reduction		Smoke-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)	2020–2030	261	183 to 339	265	188 to 341	87	58 to 123	1	0.39 to 0.77	300	233 to 368
	2031–2040	1780	1360 to 2210	1800	1380 to 2220	441	285 to 643	14	10 to 17	1890	1500 to 2300
	2020–2040	2040	1540 to 2550	2060	1570 to 2560	528	344 to 764	14	10 to 18	2200	1740 to 2650
Female non-Māori (n=2 132 141 in 2020)	2020–2030	281	196 to 367	285	201 to 370	97	64 to 138	0	0.31 to 0.62	324	252 to 401
	2031–2040	1940	1450 to 2430	1960	1480 to 2440	496	321 to 729	9	6.1 to 12	2070	1620 to 2530
	2020–2040	2220	1650 to 2800	2240	1680 to 2810	594	384 to 867	9	6.4 to 12	2390	1870 to 2920
Male Māori (n=425 740 in 2020)	2020–2030	140	97 to 183	142	101 to 184	49	32 to 69	0	0 to 0.01	163	127 to 200
	2031–2040	864	651 to 1070	873	661 to 1080	221	145 to 321	4	2.6 to 4.8	921	726 to 1120
	2020–2040	1000	747 to 1260	1010	765 to 1260	270	176 to 389	4	2.6 to 4.8	1080	851 to 1310
Male non-Māori (n=2 099 493 in 2020)	2020–2030	329	229 to 431	333	236 to 433	113	75 to 160	0	0.12 to 0.28	380	298 to 468
	2031–2040	1970	1500 to 2440	1990	1520 to 2450	504	330 to 734	4	2.6 to 5	2110	1670 to 2540
	2020–2040	2300	1730 to 2860	2320	1760 to 2870	617	405 to 892	4	2.7 to 5.3	2490	1980 to 3000
All (n=5 086 322 in 2020)	2020–2030	1010	707 to 1320	1020	728 to 1320	346	230 to 491	1	0.84 to 1.6	1170	911 to 1430
	2031–2040	6560	4990 to 8160	6620	5060 to 8190	1660	1080 to 2420	30	22 to 37	6990	5520 to 8470
	2020–2040	7570	5680 to 9440	7640	5780 to 9490	2010	1310 to 2900	31	23 to 39	8150	6450 to 9890

*Deaths averted over the period, that is, total deaths over each 10-year period in BAU minus intervention.
BAU, business as usual; UI, uncertainty interval.

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[26] is:

$$PIF_{idt} = \frac{\sum_{j=1}^{n} P_{ijt}RR_{idj} - \sum_{j=1}^{n} P'_{jt}RR_{idj}}{\sum_{j=1}^{n} P_{ijt}RR_{idj}}$$

where: i subscripts each sex by age by ethnic group, d subscripts each disease, t subscripts each time step or yearly cycle, j subscripts n states 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 (eg, by sex and age, but not by ethnic group (note the RR does not vary by time step t), and P (P') is the proportion of the demographic cohort (i) in each of j states in each 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 online supplemental appendices A and B and tables S3–S19. Harm from vaping was modelled as 5%–20% of tobacco harm following Mendez and Warner[27] (beta distribution with median 11% and 95% uncertainty interval (UI) of 5% to 20%).

Interventions

To parameterise the intervention scenarios, we considered initial estimates of potential effects based on A/NZ-specific and international literature.[28] This information, along with consideration of other more recent literature, was used in an expert knowledge elicitation process for the impact of denicotinised cigarettes on net cessation (above BAU cessation) in the A/NZ context (see online supplemental appendix D). The intervention specifications are shown in table 2; below we give key parameters and their UIs that are sampled from in Monte Carlo simulation. Briefly:

- Denicotinisation: initiation was estimated to be reduced by 90% (95% UI: 78.5% to 97.4%) compared with that in BAU by 5 years after implementation; cessation transition probabilities were increased so that over 5 years, the smoking prevalence in CS and DU states was reduced by 84.8% (95% UI: 67.1% to 96.3%) compared with that in BAU, and from the sixth year onward, cessation transition probabilities were doubled (see online supplemental appendix D for details).
- Denicotinisation plus mass media: as above, plus an extra increase in cessation rates in the first 5 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[29] of increasing travel time, converted to cost and then through price elasticities that estimate a 15.8% reduction in smoking prevalence in the year of implementation, (b) 23.0% of respondents (people who smoke) 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%; 95% UI: 12.9% to 26.9%) 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 is uncertain, so we specified that future initiation rates will be 10% of BAU, or a 90% reduction compared with BAU with wide uncertainty (95% UI: 78.5% to 97.4%), achieved 10 years after the policy is introduced.

Analyses and parameter uncertainty

We produced the following outputs. First, all and premature (before the age of 75 years) deaths averted by time period. Second, 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 those aged 45+ years old (by age in the future), under BAU and each intervention, and presented the percentage difference in the rate difference for each intervention compared with BAU.

The BAU and each intervention scenario were simulated 2000 times using Monte Carlo simulation, drawing from the probability density functions specified in table 2.

To help understand the uncertainty in our modelling, we also used univariate sensitivity analyses to depict which input parameter uncertainty generates the most uncertainty in lifetime HALY gains for all sex and ethnic groups combined for the combination endgame policy package compared with BAU. The result is presented as a 'tornado plot' showing the changes in model outputs for selecting the 2.5th and 97.5th percentile of each input parameter in turn (holding all other inputs at their expected value).

RESULTS

Achieving <5% prevalence

The modelled combined package achieves a profound and rapid reduction in smoking prevalence (figure 1 and online supplemental table 23). In 2022, the year before policy implementation, Māori age 20+ years smoking prevalence is 31.8%, falling to 28.7% (95% UI: 25.5% to 30.4%) 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 7.3% (95% UI: 3.9% to 9.2%) in 2025 (females: 8.2%, 95% UI: 4.3% to 10.5%; males: 6.3%, 95% UI: 3.4% to 7.9%). For non-Māori, the smoking prevalence is 11.8% in 2022, falling to 10.8% (95% UI: 9.6% to 11.2%) in 2025 under BAU and decreasing to 2.7% (95% UI: 1.4% to 3.5%) under the combined package (females: 2.5%, 95% UI: 1.3% to 3.3%; males: 2.9%, 95% UI: 1.5% to 3.8%). The combined package achieves the under 5% smoking prevalence target in 2026 and 2027 for Māori males and females, respectively.

Denicotinisation causes the majority of forecasted 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 policy package, deaths up to 2040 were 8150 (95% UI: 6450 to 9890) less than under BAU, with 27%–30% of these averted deaths among each of female Māori, female non-Māori and male non-Māori (table 3). Premature deaths averted (ie, deaths occurring before 75 years) up to 2040 were 8540 (95% UI: 6780 to 10 400), a 0.97% (95% UI: 0.77 to 1.17) reduction compared with BAU (online supplemental tables S24–S25).

HALYs gained

For the combined intervention compared with BAU, by sex and ethnic group, 28%–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 594 000 HALYs gained (95% UI: 443 000 to 738 000: 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 18% and the tobacco-free generation alone 13%. For the tobacco-free generation, the vast majority (98%) of HALYs gained over the lifespan of the population occurred after 2040. Online supplemental figure S3 provides a comparison in terms of health gains from the endgame strategies evaluated in this paper with other large-scale public health policies (modelled or already in place) in A/NZ.

Inequality impacts

Figure 2 shows the ratio of age-standardised per capita HALY gains for Māori compared with 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 that the absolute gains were less for this strategy—see online supplemental table S26).

Mortality rates of Māori aged 45+ years in 2040 are 11.6% and 5.2% lower under the combined package than under BAU, for females and males, respectively. 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 with non-Māori 'gap' (absolute difference) in mortality rates by 2040 is shown in figure 3. The rate difference is 23.4% (95% UI: 19.1% to 27.6%) less for females for the combined package compared with BAU, and 9.5% (95% UI: 7.5% to 11.3%) 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.

Sensitivity analyses for the denicotinisation policy at the lower end of effectiveness (ie, 97.5th percentile values of: the percentage reduction in smoking prevalence due to increased cessation over and above BAU of 67.1%, and the percentage reduction in initiation of 78.5%), and retail outlet reduction and the tobacco-free generation set to their expected or median input values, the total HALY gains for the combined package reduced by 13.6% to 513 000 compared with expected values for all inputs. The contribution of retail outlet reduction and the tobacco-free generation alone compared with the combined package was 19% and 29%, respectively, a higher relative contribution compared with 18% and 13% in the main model (see online supplemental table S27).

Figure 4 shows a tornado plot of how much variation in lifetime HALYs gained (combined endgame policy; 3% discount rate) resulted from univariate sensitivity analyses about the key intervention parameters. Uncertainty about the cessation rate due to denicotinisation was clearly the major source of overall uncertainty in HALYs gained: the 97.5th percentile value of increased cessation leading to 32.9% of BAU smoking prevalence (or conversely a 67.1% reduction in smoking prevalence due to increased cessation) led to 545 000 HALYs gained (end of blue bar in figure 4) compared with 653 000 HALYs gained (end of red bar) for the 2.5th percentile value of 3.7% of BAU smoking prevalence due to cessation (or conversely a large 96.3% reduction in smoking prevalence due to increased cessation). Uncertainty about other key input parameters generates considerably less uncertainty in the HALYs gained.

DISCUSSION

In A/NZ, a post-colonial country with a high smoking rates among the Māori, we found that tobacco endgame strategies outlined in the December 2021 A/NZ Smokefree Plan,[13] in particular

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		Smoke-free generation		Combined interventions	
		Estimate	95% UI	Estimate	95% UI	Estimate	95% UI	Estimate	95% UI	Estimate	95% UI
Female Māori	2020–2030	955	679 to 1260	971	699 to 1260	335	221 to 475	23	16 to 31	1130	884 to 1380
	2031–2040	10 600	7990 to 13 100	10 700	8160 to 13 100	2800	1830 to 3990	325	242 to 406	11 500	9370 to 13 700
	2041–2131	151 000	111 000 to 188 000	151 000	112 000 to 189 000	24 800	15 900 to 36 700	29 900	19 400 to 40 600	157 000	116 000 to 195 000
	All	162 000	120 000 to 202 000	163 000	121 000 to 203 000	27 900	18 000 to 41 100	30 300	19 700 to 41 000	170 000	127 000 to 210 000
Female non-Māori	2020–2030	1450	1030 to 1940	1470	1050 to 1950	525	346 to 745	23	16 to 32	1710	1330 to 2130
	2031–2040	14 700	11 000 to 18 300	14 800	11 200 to 18 400	3990	2610 to 5770	334	239 to 443	16 000	12 800 to 19 200
	2041–2131	142 000	104 000 to 182 000	143 000	105 000 to 182 000	28 200	17 800 to 42 800	15 300	9950 to 22 400	149 000	109 000 to 189 000
	All	159 000	116 000 to 201 000	160 000	117 000 to 202 000	32 700	20 800 to 49 200	15 600	10 300 to 22 900	166 000	124 000 to 209 000
Male Māori	2020–2030	596	423 to 786	606	436 to 792	214	141 to 303	17	12 to 22	707	554 to 871
	2031–2040	6080	4570 to 7520	6140	4670 to 7560	1640	1070 to 2350	230	171 to 291	6650	5360 to 7940
	2041–2131	70 100	49 400 to 90 600	70 500	49 600 to 91 000	12 400	7990 to 18 800	12 800	8220 to 18 100	73 600	52 100 to 94 200
	All	76 700	54 800 to 98 300	77 200	55 300 to 98 800	14 300	9240 to 21 400	13 000	8450 to 18 300	80 800	58 200 to 103 000
Male non-Māori	2020–2030	1620	1140 to 2150	1640	1170 to 2160	585	384 to 830	24	16 to 33	1910	1500 to 2360
	2031–2040	15 900	12 000 to 19 700	16 000	12 200 to 19 800	4300	2810 to 6180	345	249 to 455	17 300	14 000 to 20 800
	2041–2131	151 000	112 000 to 193 000	152 000	112 000 to 193 000	29 500	18 900 to 44 400	16 300	10 800 to 23 800	158 000	119 000 to 199 000
	All	168 000	126 000 to 214 000	169 000	127 000 to 214 000	34 400	22 100 to 51 400	16 700	11 100 to 24 300	177 000	134 000 to 221 000
All population	2020–2030	4630	3260 to 6140	4690	3360 to 6170	1660	1090 to 2360	88	60 to 118	5460	4280 to 6740
	2031–2040	47 400	35 700 to 58 500	47 800	36 400 to 58 700	12 700	8300 to 18 300	1230	909 to 1590	51 500	41 500 to 61 600
	2041–2131	514 000	378 000 to 650 000	517 000	380 000 to 653 000	94 800	60 900 to 143 000	74 200	49 000 to 104 000	537 000	396 000 to 673 000
	All	566 000	421 000 to 711 000	569 000	424 000 to 714 000	109 000	70 200 to 163 000	75 500	50 200 to 105 000	594 000	443 000 to 738 000

HALYs, health-adjusted life years; UI, uncertainty interval.

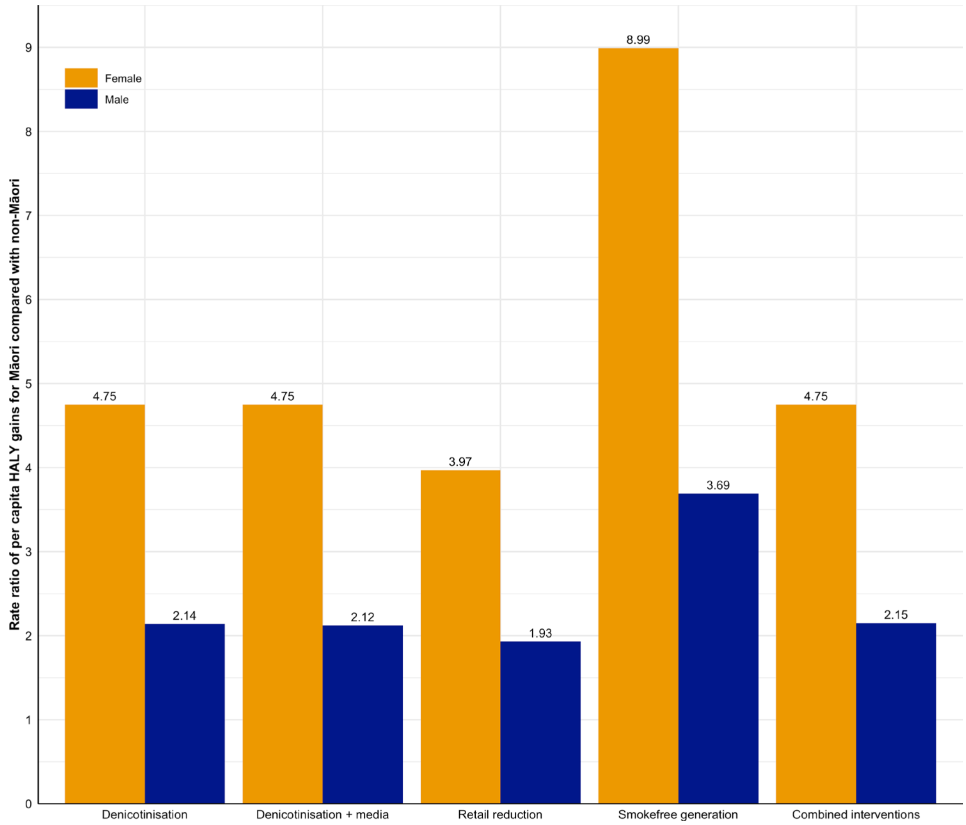

Figure 2 Ratios of per capita HALY gains over the remainder of the 2020 Aotearoa/New Zealand population's lifespan, for Māori compared with non-Māori. Calculated using cohorts defined by age in 2020, age standardised using the 2020 Māori population. HALY, health-adjusted life year.

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, by 2040, a combined package including denicotinisation plus media, 95% reduction in retail outlets and a tobacco-free generation would—we estimate—reduce the gap in the mortality rate of people aged 45 years and older by 23.4% (95% UI: 19.1% to 27.6%) for females and 9.5% (95% UI: 7.5% to 11.3%) for males, compared with ongoing BAU. It is unlikely that any other feasible health intervention would reduce ethnic inequalities in mortality by as much.

Our forecasts 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,[19] greater than interventions such as mass media and quit programmes alone,[30] and a tobacco-free generation will be relatively more important in terms of health benefits if the impact of the denicotinisation policy is at the lower end of our uncertainty range (see sensitivity analyses above).

The profound impact of tobacco endgame strategies on ethnic health inequities in A/NZ shown in the model 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.[31] While 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 Gross Domestic Product (GDP) 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/NZ's Action Plan have 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, robust evaluations are conducted to better inform decision-making and improve modelled estimates such as the current study. Second, such evaluations should thoroughly investigate equity issues, exploring intended and unintended impacts on Indigenous peoples. Third, the striking equity impacts of endgame interventions estimated here, future tobacco control modelling studies should explore impacts on inequities in smoking prevalence and smoking-related disease.

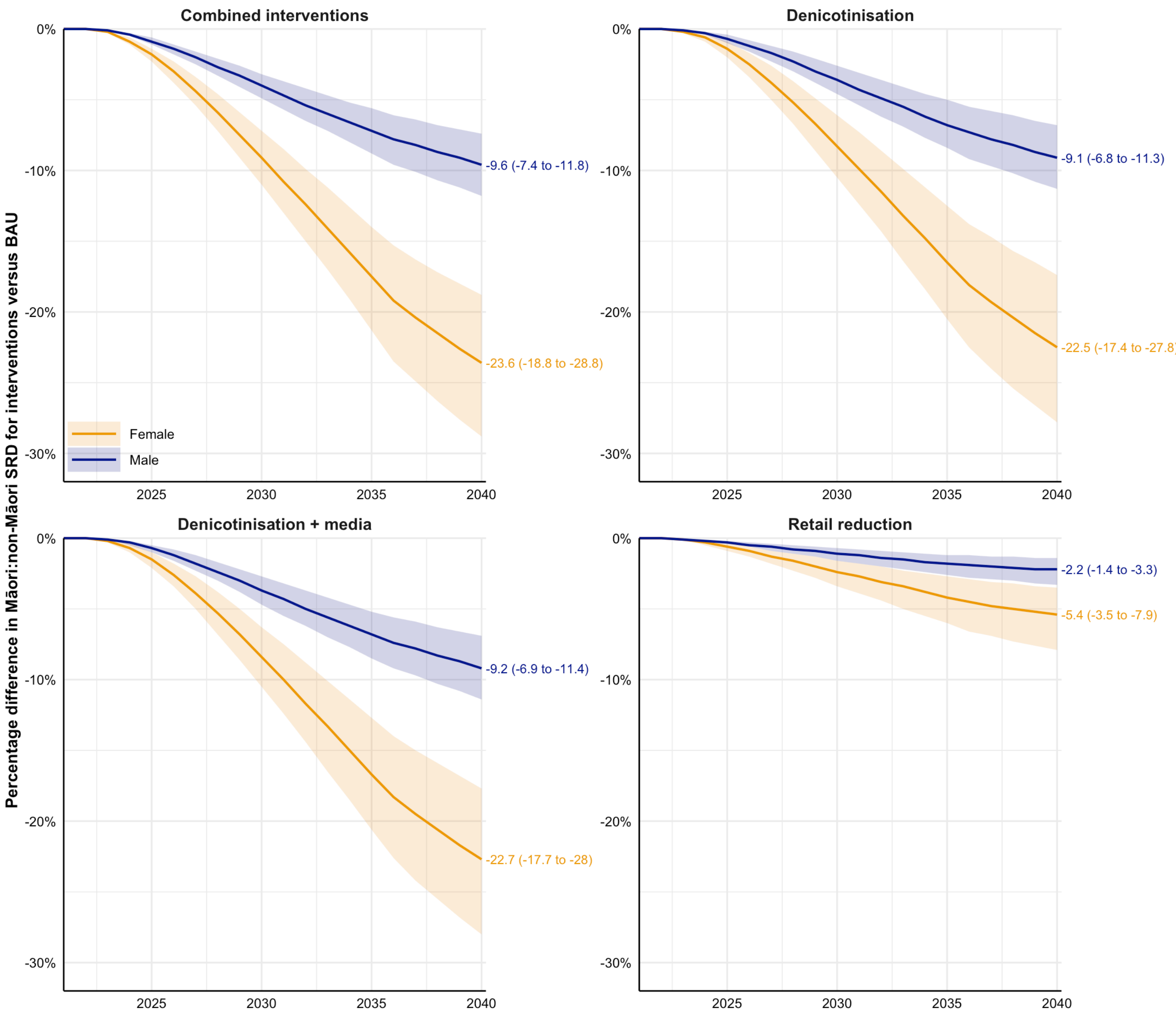

Figure 3 Projected percentage changes in age-standardised all-cause mortality rate differences (≥45 years) between Māori and non-Māori, for endgame strategies* compared with BAU. *We do not show the tobacco-free generation as there is no change in mortality rates of those aged 45 plus years old in this timeline. Rates are standardised to the Māori population. BAU, business as usual; SRD, standardised rate difference.

Limitations

Given data limitations, expert judgement and estimates from scenario studies were used in specifying the impacts of endgame policies. We specified substantial uncertainty about most of these inputs (table 2), then used Monte Carlo simulations to generate uncertainty about the outputs of HALYs gained and mortality impacts. The UIs of the HALYs, for example, are non-overlapping between the denicotinisation and retail interventions, and with BAU, suggesting a strong degree of confidence in the ranking of health gains and inequity impacts. Univariate sensitivity analyses for the combined interventions policy package (figure 4) clearly show that input uncertainty about how much denicotinisation will reduce cessation drives much of the uncertainty in the outputs of our modelling. That said, even for this cessation impact varying widely from a 67.1% to 96.3% reduction in prevalence, the lifetime HALY gains were always substantial (range: 545 000–653 000).

Our BAU scenario of future smoking prevalence was based on trends from 2013 to 2014 to 2019–2020. The 2020–2021 Health Survey results showed a notable downturn in smoking prevalence—that has continued in the 2021–2022 prevalence estimates (see the Introduction section). If the drops in the last 2 years are not partially anticipatory effects of the Action Plan policies, then one could argue that the BAU we used is too high in future smoking prevalence, the corollary of which is that the health gains due to the endgame policies in this paper are overestimated (as some of the gains we attribute to the policies were already occurring under BAU).

Our model assumes that all smoking uptake occurred at age 20 years, and reports smoking prevalence for those aged 20+ years old; had we used 15+ years old as our denominator, the smoking prevalence results reported would have been lower. Our modelling quantified the separate effects of each policy, and their combined effect by simply adding them simultaneously to the modelling. Estimating impacts of temporal ordering of policies (eg, whether to implement denicotinisation or retail outlet reduction first) was beyond the scope of our modelling.

Contextual variations for A/NZ compared with other countries (strong border controls, likely minor illicit tobacco market, ready

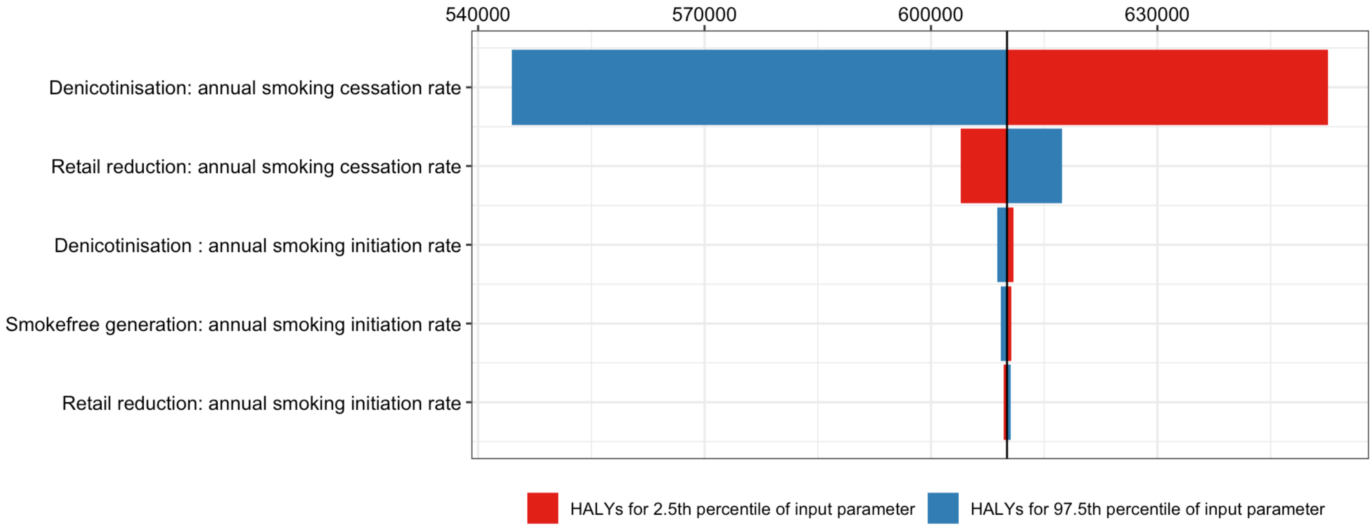

Figure 4 Tornado plots of total HALYs (3% discount, lifetime) showing the ranking of smoking initiation and cessation parameters by how much uncertainty their 2.5th and 97.5th percentiles cause for the combined intervention policy package compared with BAU, for: percentile values for sensitivity analyses (taken from table 2): *Denicotinisation: annual smoking cessation rate*. Cessation rates in first 5 years after policy implementation set to achieve 3.7% (2.5th percentile) or 32.9% (97.5th percentile) of BAU smoking prevalence (median=14.1%). *Retail reduction: annual smoking cessation rate*. One-off (in year of implementation) increase in cessation rate of 12.9 percentage points (2.5th percentile) or 26.9 percentage points (97.5th percentile) (median=19.2 percentage points). Note: when combined with denicotinisation (above), it acts on top of the 'new' (not BAU) denicotinisation cessation rate. *Denicotinisation: annual smoking initiation rate*. Initiation rate 5 years after policy implementation reduced to 2.6% (2.5th percentile) or 21.5% (97.5th percentile) of BAU initiation rates (median=9.3%). *Smoke-free generation: annual smoking initiation rate*. Initiation rate 5 years after policy implementation reduced to 2.6% (2.5th percentile) or 21.5% (97.5th percentile) of BAU initiation rates (median=9.3%). Note: when combined with denicotinisation (above), it acts on top of the 'new' (not BAU) denicotinisation cessation rate. *Retail reduction: annual smoking initiation rate*. Permanent decrease in initiation rate of 12.9% (2.5th percentile) or 26.9% (97.5th percentile) (median=19.2%). Note: when combined with denicotinisation and smoke-free generation (above), it acts on top of the 'new' (not BAU) initiation rate. Note: the vertical black line of 610 073 HALYs is for the median value of all input parameters. It differs modestly from the 594 000 central estimate of HALYs in the main analyses, which is the median across all iterations of the Monte Carlo analyses. BAU, business as usual; HALYs, health-adjusted life years.

access to vaping as a lower-cost substitute) may have contributed to the expert parameterisation of the cessation and initiation impacts in this modelling paper being more optimistic than a previous Food and Drug Administration (FDA) expert knowledge elicitation for the USA[32] (online supplemental appendix D). Those estimates of cessation due to mandatory denicotinisation ranged from 20.6% to 99.9% (average across experts 77.2%). Our experts ranged from 78.5% to 95% in their 'most likely' estimates of quitting after 5 years and averaged 65.8% and 96.6% for their pessimist and optimistic estimates, respctively. However, our assumption of a 90% (95% UI: 78.5% to 97.4%) reduction in initiation due to mandatory denicotinisation was higher than the FDA experts (range: 45%–95% across experts).

The paper did not explicitly model the impact of the illicit market. However, homegrown tobacco is uncommon in A/NZ due to a non-ideal environment for growing. Furthermore, tight border security in an island nation with no land borders reduces the potential of an illicit market. Nevertheless, we may have modestly overestimated health gains and smoking prevalence reductions if—say—smoking prevalence was to asymptote to something like 1%–3%, rather than 0%. An important corollary is that achieving the health gains and health inequity reductions modelled in our paper will require strong border control, and comprehensive support for people who smoke to quit (or use alternative nicotine delivery products as a substitute).

We have highlighted the importance of Māori and Indigenous engagement in the development and implementation of the A/NZ's 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 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 prioritising dissemination of findings to Māori communities first.

CONCLUSION

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

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Contributors Our team brings Māori lived experience (AW), Indigenous lived experience (RM, RL) and experience in research on tobacco inequalities (AW, RM, CEG, RL, RE, NW, TB). DAO, JAS, 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 contributed to data interpretation. AW, RM and RL initiated the drafting of the Introduction and Discussion sections; TB led the Methods and Results sections; and DAO led the appendices. All authors revised the draft manuscript critically for important intellectual content. DAO is guarantor of the study and accepts full responsibility for its conduct and overall content.

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Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplemental information. All data used in the model are publicly available and their references provided in the manuscript.

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