

Indoor Combustion in New Zealand Homes: Health Effects and Costs - Peer Review Report

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Introduction

The Energy Efficiency and Conservation Authority (EECA) has commissioned a report titled “Indoor Combustion in New Zealand Homes: Health Effects and Costs” (the Indoor Combustion report) to attempt to quantify the health effects and costs of indoor air pollution arising from various household combustion appliances.¹ The report was completed by *Emission Impossible Ltd.*, a leading research organisation in the field of air pollution and health harms in Aotearoa New Zealand, in conjunction with *Resource Economics*, a consulting firm with experience in economic modelling on natural and urban environments.

This document is an independent peer review of the final report, model and supplementary documents to provide assurance of the validity of the report’s findings and recommendations, verify the accuracy of the input data and model, and discuss the potential implications of the findings for public health, housing and energy policy. The author is a Public Health Medicine Specialist, and EECA requested that the report is written particularly from the point of view of public health policy and epidemiology.

Overall Assessment

For this peer review, EECA has posed three questions related to the Indoor Combustion Report, which are answered here and supported by the analysis of each element of the research in the body of this review.

1. Are the findings credible?

Overall, the Indoor Combustion Report is a robust, evidence-based and methodologically-sound research report, and the findings are credible. Key methodological decisions are justified and in line with practice in similar international, peer-reviewed research. As discussed in this review, where opportunities for refinement of the research are highlighted, the effect of making these refinements would likely

¹ Metcalfe J., Kuschel G., Wickham L., and Denne T., (2025). *Indoor Combustion: Health Effects and Costs*. Report prepared by Emission Impossible Ltd and Resource Economics for Energy Efficiency & Conservation Authority, June. 2025.

significantly increase the estimate of health harms and economic costs. As such the results presented in the Indoor Combustion Report are essentially a minimum “floor” for health harms and costs associated with indoor air pollution, and presentation of the results should frame them as a low estimate.

2. Is the evidence strong enough to inform policy decisions?

Given the answer to Question 1 and the magnitude of the health harms and fiscal/economic costs estimated in the Indoor Combustion Report, it is my opinion that the evidence is strong and should be used to inform policy decisions across government. As the report highlights, even taking the “low” scenario values (the lowest credible estimates of exposure and harm in the model) results in “appreciable” health impacts and economic costs, which would provide ample justification for policy decisions.

3. Are the findings out of line with other international reviews?

The findings of the Indoor Combustion Report are largely in line with international research, particularly four major recent papers studying the health harms of indoor air pollution globally, in the USA, the UK/EU and Australia. Where the findings differ from these international reports (i.e. the population-attributable fraction for asthma attributable to gas stoves), this is **lower** than international findings.

Summary of the Indoor Combustion Report

Emission Impossible Ltd. and *Resource Economics* were commissioned to examine the health effects and monetised costs associated with air pollution arising from the use of three classes of indoor combustion appliances: gas stoves, wood burners, and unflued gas heaters (gas heaters that do not have a “flue” (chimney or ducted exhaust) to the exterior environment). The wood burners considered range from open fireplaces to modern low-emission enclosed burners.

The report is comprised of three main components:

1. A literature review aimed at gathering reasonable model inputs related to:
 - a. Levels of particular air pollutants found in New Zealand homes with the use of the three indoor combustion appliances
 - b. The actual utilisation of these appliances in New Zealand homes
 - c. The health harms that can be attributed to these pollutants
2. A health effects model where the inputs from the literature review and other data sources were used to calculate the health harms attributable to each appliance type across all of New Zealand
3. A costing model where the output of the health effects model are used to estimate the fiscal costs (i.e. those the government pays like hospitalisations) and the economic costs (i.e. the actual total costs, including lost life years, lost productivity, costs on individuals from ill health) attributable to each appliance type across all of New Zealand

Assessment

Overall this is a reasonable and logical approach to answering EECA’s desired research questions. The approach is in line with EECA’s original tender document and *Emission Impossible Ltd.* and *Resource Economics*’ RFP response document. *Emission Impossible Ltd.* is well-regarded in the environmental health sector and an established air pollution research provider in New Zealand, notably having led the Health and Air Pollution in New Zealand (HAPINZ) series of research projects in conjunction with University-based researchers, which are landmark publications in the field of health harms attributable to air pollution.

The overall outputs of the report have a range of applications:

- The health sector and the Ministry of Health have a clear interest in preventing health harms, and this is a legislated function for Crown Entities under the Pae Ora (Healthy Futures) Act 2022 The Ministry of Health and Health New Zealand | Te Whatu Ora already work in the housing sector through programmes such as the Healthy Housing Initiative, where heating appliances are considered for their

potential health harms.² As such there are both policy/strategic and operational impacts of this knowledge on health sector organisations.

- Housing regulators such as the Ministry for Business, Innovation and Employment (MBIE) also have an interest in reducing fiscal costs to government and total economic costs as part of policy stewardship and their role in promoting economic development.
- The fiscal costs calculated may be a candidate for inclusion in the New Zealand Treasury's Cost-Benefit Analysis (CBAX) tool, which various agencies use to calculate the fiscal and economic costs and benefits of policies. This tool already includes costs attributable to sources of outdoor air pollution, and monetises the avoidance of health events such as hospitalisations, GP visits and prescriptions.
- Housing agencies such as Kāinga Ora and Community Housing Providers have an interest in providing housing environments that promote the wellbeing of occupants.
- The public has an interest in receiving reliable information about the health risks attributable to their housing environment and use of indoor combustion appliances. When building or renovating homes, choosing types of heating and cooking represent major investments.
- The housing construction sector has an interest as healthy homes have value that can be realised, and it is relatively difficult to retrofit gas and woodburner appliances so installing the healthiest appliances during construction is the most efficient approach from a society-wide point of view.

The Literature Review

The literature review performed in the Indoor Combustion report was a three-step process:

1. A high-level literature scan aimed at identifying systematic reviews and other authoritative reports on the topic of indoor combustion appliances and health outcomes, as well as levels of indoor pollutants in New Zealand homes. This step was not designed to identify every individual relevant research report, but to develop an overview of the state of research. This step identified major reports from agencies such as the World Health Organization, Public Health England, the Institute for Health Metrics and Evaluation (responsible for the Global Burden of Disease Study), and the American Lung Association, as well as robust peer-reviewed studies on health impacts across the EU/UK and USA. These reviews included synthesis of thousands of previous studies.

² <https://www.tewhatauora.govt.nz/health-services-and-programmes/healthy-homes>

2. A systematic review of the literature designed to identify New Zealand and Australia-specific research on the health effects of indoor combustion appliances. This was to ensure the review was relevant to the New Zealand appliance use context and that all relevant local research was identified, as the high-level reviews in step 1 may have missed very recent or local research.
3. A manual search of the studies included in steps 1 and 2 to find “exposure data” that could be used to estimate the relationship between indoor combustion appliance use and levels of exposure to pollutants for the occupants of the homes. This data is important for the health effects model as there is New Zealand-specific data on the proportion of homes with indoor combustion appliances, but the level of pollutant exposure in these homes must be estimated from research.

The report splits the findings into three sections – overall research on indoor air quality, overall research on the health effects of indoor gas cooker use, and overall research on health effects of indoor wood burner use.

Assessment

The literature review is well-documented and takes a sensible and efficient approach to synthesising the current state of knowledge and discovering inputs for the health effects model. Rather than undertaking a systematic review on the entirety of the air pollution and health literature, the approach of synthesising existing overarching reviews and then focusing their review on recent local research and extracting specific exposure data represents a good use of effort and resources.

The systematic review was conducted in accordance with the PRISMA framework, the gold-standard for systematic review methodology. The review used EBSCOhost, which aggregated multiple research databases that could have relevant research, including medical, environmental and engineering specific collections. The search strategy likely covers the breadth of relevant research on gas cookers and woodburners – repeating the search in PubMed and varying the search terms found no additional important studies up to February 2025 (the time the search was conducted).

The papers included as “Key Resources” are all high-quality reviews, modelling research reports and other types of peer-reviewed research. They are recent and generally conducted in countries that are comparable to New Zealand. Journal articles are published in reputable journals with high-quality peer review and publishing processes. The Gillespie-Bennet et al. and Trompetter & Davy papers are the best choices for inputs to the model for indoor air pollution as they are direct measures taken in real-world, representative New Zealand houses.

There is not a specific section for the health effects of gas heating in the literature review, and there was not a specific search conducted that was designed to find

research specific to gas heating, as opposed to general use of gas combustion indoors. This was covered somewhat by one of the key studies (Puzzolo et al.) which reviewed and meta-analysed literature on both gas cooking and gas heating, and sometimes combined these measures in its analyses. Performing a Pubmed search using “gas heating” in place of the gas cooking-related search terms employed does elicit a few relevant references that do not appear in the documentation of the literature search.^{3,4,5}

The section on indoor air could be improved by commenting on existing guidance for indoor air quality, and the range of contaminants that are of potential concern. For example, Health Canada has published guidelines for residential air quality by pollutant, including for nitrogen dioxide.⁶ This resource discusses epidemiological evidence, gives some reference values for typical NO₂ concentrations in Canadian homes, and recommends short and long-term concentration limits.

Apart from NO₂, using gas (liquefied petroleum gas or natural gas delivered by reticulation) also results in the production of water and carbon dioxide, as well as benzene, methane and carbon monoxide.⁷ While it was agreed that the report would focus on PM_{2.5} and NO₂ and these other emissions are not the focus of the study, and it is likely infeasible to robustly model these pollutants with currently available data, it would be helpful for the literature review to comment on these other pollutants and their potential role in confounding the ERFs selected. The report does discuss that using ERFs derived for outdoor NO₂ exposure may introduce inaccuracy when applied indoors because the ERF likely represents some contribution from other traffic-related pollutants. There may be a similar situation indoors where, for example, the increase in humidity (and accompanying favourable environment for black mould growth), or small amounts of benzene or CO may also contribute to health effects of indoor combustion appliance use. Using outdoor NO₂ ERFs could therefore underestimate the harm of indoors because there are additional effects not being accounted for.

³Franklin PJ, Loveday J, Cook A. Unflued gas heaters and respiratory symptoms in older people with asthma. *Thorax*. 2012 Apr;67(4):315-20. doi: 10.1136/thoraxjnl-2011-200236. Epub 2012 Jan 16. PMID: 22250101.

⁴Pilotto LS, Nitschke M, Smith BJ, Pisaniello D, Ruffin RE, McElroy HJ, Martin J, Hiller JE. Randomized controlled trial of unflued gas heater replacement on respiratory health of asthmatic schoolchildren. *Int J Epidemiol*. 2004 Feb;33(1):208-14. doi: 10.1093/ije/dyh018. PMID: 15075170.

⁵Phoa LL, Toelle BG, Ng K, Marks GB. Effects of gas and other fume emitting heaters on the development of asthma during childhood. *Thorax*. 2004 Sep;59(9):741-5. doi: 10.1136/thx.2003.014241. PMID: 15333848; PMCID: PMC1747141.

⁶<https://www.canada.ca/en/health-canada/services/publications/healthy-living/residential-indoor-air-quality-guideline-nitrogen-dioxide.html>

⁷Seltenrich N. Clearing the Air: Gas Stove Emissions and Direct Health Effects. *Environ Health Perspect*. 2024 Feb;132(2):22001. doi: 10.1289/EHP14180

The Health Effects Model

The Health Effects Model can be simply represented as the following steps:

1. Data on the number of households with indoor combustion appliances is sourced from Stats NZ and the Rewiring Aotearoa Machine Count
2. Some assumptions about the number of people per household are made and multiplied by the number of appliances
3. This number of exposed people is modified by an **exposure increment** i.e. the additional amount each person is exposed to a pollutant if they use an appliance, compared to a non-user. These exposure increments are derived from the papers in the literature review that directly measured levels of pollutants in houses, mostly in New Zealand.
4. Some modifications are made for seasonal differences in appliance use - heaters are used less in non-winter months, while better ventilation in summer reduces the NO₂ accumulation from stove use – these modifications are based on measured New Zealand data.
5. This total person-exposure value is combined with the existing incidence of health outcomes and the ERFs derived in the literature review for each appliance-health outcome pair (8 outcomes and 11 appliance-outcome pairs) to calculate the total number of additional health outcomes attributable to the use of each indoor combustion appliance.

Steps 2,3 and 4 also have “low” and “high” scenarios based on the 95% confidence intervals of the estimates used as inputs to the model. These are the lowest and highest credible values and can differ significantly from the central estimates. It is most likely the true values lie closer to the central estimate than the upper and lower bounds, so the central estimates should be treated as the most reliable, while the low and high scenarios should be used as “what-if” scenarios. If the lowest scenario estimate is still billions of dollars of health costs (as is the case in the report), this adds confidence to the assertion that indoor air pollution is a significant public health and economic issue that warrants policy action.

There is an additional “sense-check” model of the contribution of indoor combustion to outdoor pollution – this is done by multiplying the number of appliances with their estimated fuel use, and a factor for outdoor emissions (i.e. the proportion of emissions each appliance emits outdoors), then multiplying these volumes of emissions by the damage costs (updated to 2025 dollars) from the HAPINZ3.0 study.

Assessment

The Health Impacts model (an Excel spreadsheet) was supplied for the purpose of this review. It is well-documented, transparent and logically structured – all claims made in

the text of the review match with the calculations. There are additional analyses and “sense-checking” activities in the model that provide greater confidence in its validity, such as a comparison between the Exposure Response Function (ERF) selected for asthma prevalence and the ERF published in the Puzzolo meta-analysis.

Key decisions and assumptions in the construction of the model are well-documented and justified. These include:

- Using ERFs established for outdoor exposure for indoor pollution
 - This is the approach used in multiple major international epidemiological studies (i.e. papers by Delgado-Saborit, Kashtan, and Bennitt examining effects of indoor pollution across the EU/UK, USA and globally) published in prominent journals such *the Lancet* and *Science*.
- Separating indoor pollution from ambient outdoor pollution (i.e. asserting that the health impacts of indoor air pollution are not just attributable to pollutants in outdoor air coming into the indoor environment)
 - Several studies in the literature review that directly measured indoor air pollutants found no correlation with outdoor air pollution. This approach has also been taken by the three international studies mentioned above as their own investigations of the literature did not find significant relationships between outdoor and indoor air pollution.
- The approach to seasonal variation
 - Reliable sources are used to provide modifiers for how much indoor combustion appliances are used across seasons.
- The approach to assigning harms to the various sub-types of woodburners
 - The report derives averages from estimates from multiple studies that directly measured emissions from various woodburning appliances, ranging from open fires to modern low-emissions burners. Where possible this was cross-checked with a New Zealand-specific study (Trompetter & Davy) conducted by GNS Science.
- Estimating the relative proportions of woodburner types across households within the high-level Census category of “wood burner”
 - This issue is addressed by applying estimates from Canterbury to the whole country – the database these figures come from is not publicly available so it is difficult to comment on whether this might introduce some bias. If anything, Canterbury homes might be more likely to have modern wood burners given the extensive building and home repairs that followed the Canterbury earthquake, but this is speculative.

The inclusion of a model of the outdoor air pollution effects of the indoor combustion appliances is well-considered, and provides a useful point of comparison and context.

Health Outcomes Selection

The health effects model focuses on the health impacts of two main pollutants: PM_{2.5} and nitrogen dioxide (NO₂). This is a reasonable choice given the relative paucity of data on indoor exposure to other pollutants (e.g. benzene, polycyclic aromatic hydrocarbons, ozone) in New Zealand, and the lack of established relative risks for these pollutants on health harms.

The model focuses on the same health harms employed by the HAPINZ3.0 study, namely:

- Premature mortality or years of life lost for people over 30
- Cardiovascular hospitalisations for all ages
- Respiratory hospitalisations for all ages
- Restricted activity days for all ages (PM_{2.5} only)
- Asthma/wheeze hospitalisation for 0-18 year olds (NO₂ only)
- Incidence of asthma for 0-18 year olds (NO₂ only)

These are reasonable choices for health impacts of pollutants, and represent the majority of attributable health harms and fiscal/economic costs. These measures were likely chosen because the exposure-outcome relationships were already well-established in the HAPINZ3.0 study, which itself was extensively peer-reviewed and has been used for health economic modelling and policy-making in New Zealand in health, urban planning and transport spheres.

However, there are many more health outcomes proven to be related to PM_{2.5} and NO₂ exposure, both indoor and outdoor. These include specific impacts that may not be adequately captured by the above outcomes, because they are not captured under the cardiovascular/respiratory categories of hospitalisation, do not lead to hospitalisation, or do not contribute to the overall measure of premature mortality in people over 30. This point is made on page 33 of the report but it bears emphasising in this review.

These health outcomes include but are not limited to:

- Miscarriage, stillbirth, pre-term birth and low birthweight in babies whose mothers are exposed to air pollution⁸
- Poorer academic performance in adolescents⁹
- Dementia¹⁰, both Alzheimer and non-Alzheimer

⁸ Health Effects Institute. 2024. State of Global Air 2024. Special Report. Boston, MA:Health Effects Institute

⁹ Lim YH, Bilsteen JF, Mortensen LH, Lanzky LR, Zhang J, Tuffier S, Brandt J, Ketzel M, Flensburg-Madsen T, Wimmelmann CL, Okholm GT. Lifetime exposure to air pollution and academic achievement: A nationwide cohort study in Denmark. *Environment International*. 2024 Mar 1;185:108500.

¹⁰ Rogowski C, Bredell C, Shi Y, Tien-Smith A, Szybka M, Fung KW, Hong L, Phillips V, Andersen ZJ, Sharp S, Woodcock J. Long-Term Air Pollution Exposure and Incidence of Dementia: A Systematic Review and Meta-Analysis. Available at SSRN 4997922.

- Lung cancer incidence, and poorer survival in lung cancer patients¹¹
- Other cancers including breast,¹² liver,¹³ cervical and nasopharyngeal¹⁴
- Severity and likelihood of acquiring respiratory infections such as COVID-19¹⁵
- Cataracts¹⁶
- Type 2 diabetes¹⁷
- Exacerbation of heat-related morbidity and mortality¹⁸

There are also significant fiscal and economic costs associated with non-hospital healthcare service utilisation associated with all air pollution-related conditions not captured in the model, for example prescription costs (both PHARMAC subsidy and out-of-pocket expenditure by individuals), primary care appointments, laboratory/radiology tests and travel associated with accessing healthcare.

Overall, the above considerations make it likely that the Indoor Combustion report underestimates the true health impacts, and therefore fiscal and economic costs, of indoor pollution from the specified appliances.

Exposure Response Function selection

The report utilises the exposure response functions (ERFs) from HAPINZ3.0, explicitly incorporating an assumption that exposure to a certain amount of a pollutant outdoors causes the same health effects as exposure to the same amount indoors. This is a reasonable assumption and as stated, is consistent with the methods of other similar attribution studies. The ERFs in HAPINZ3.0 are based on the HAPINZ cohort paper

¹¹ Berg CD, Schiller JH, Boffetta P, Cai J, Connolly C, Kerpel-Fronius A, Kitts AB, Lam DC, Mohan A, Myers R, Suri T. Air pollution and lung cancer: a review by international association for the study of lung cancer early detection and screening committee. *Journal of Thoracic Oncology*. 2023 Oct 1;18(10):1277-89.

¹² Wei W, Wu BJ, Wu Y, Tong ZT, Zhong F, Hu CY. Association between long-term ambient air pollution exposure and the risk of breast cancer: a systematic review and meta-analysis. *Environmental Science and Pollution Research*. 2021 Nov;28(44):63278-96.

¹³ So R, Chen J, Mehta AJ, Liu S, Strak M, Wolf K, Hvidtfeldt UA, Rodopoulou S, Stafoggia M, Klompmaker JO, Samoli E. Long-term exposure to air pollution and liver cancer incidence in six European cohorts. *International journal of cancer*. 2021 Dec 1;149(11):1887-97.

¹⁴ <https://www.who.int/teams/environment-climate-change-and-health/air-quality-energy-and-health/sectoral-interventions/household-air-pollution/health-risks>

¹⁵ Hyman S, Zhang J, Andersen ZJ, Cruickshank S, Møller P, Daras K, Williams R, Topping D, Lim YH. Long-term exposure to air pollution and COVID-19 severity: A cohort study in Greater Manchester, United Kingdom. *Environmental Pollution*. 2023 Jun 15;327:121594.

¹⁶ Li X, Guo Y, Liu T, Xiao J, Zeng W, Hu J, He G, Ma W, Wu F. The association of cooking fuels with cataract among adults aged 50 years and older in low-and middle-income countries: results from the WHO Study on global AGEing and adult health (SAGE). *Science of The Total Environment*. 2021 Oct 10;790:148093.

¹⁷ Yang BY, Fan S, Thiering E, Seissler J, Nowak D, Dong GH, Heinrich J. Ambient air pollution and diabetes: a systematic review and meta-analysis. *Environmental research*. 2020 Jan 1;180:108817.

¹⁸ World Health Organization. The synergies of heat stress and air pollution and its health impacts: technical brief. Geneva: World Health Organization; 2025 (WHO Air Quality, Energy and Health Science and Policy Summaries). <https://doi.org/10.2471/B09369>

(Hales 2021)¹⁹ which are specific to New Zealand - these are broadly in line with ERFs in the Puzzolo meta-analysis for asthma, although the paper found a much higher ERF for NO₂ and mortality - 1.105 in the Hales paper cf 1.008 used in the Delgado-Saborit paper estimating mortality in the EU/UK, and 1.02 in a 2020 meta-analysis.²⁰ These differences are discussed and justified in the HAPINZ3.0 detailed methodology document.²¹ Given these values are specific to New Zealand, have been published in peer-reviewed research and used previously in research commissioned by the New Zealand government, they represent the best set of functions to use for this study.

There has been some criticism of the use of the Puzzolo ERF for asthma prevalence in other studies as it is not deemed “statistically significant”, with a p value of 0.071 rather than 0.05 or lower. For clarity, this report did not use the Puzzolo ERF, instead using an ERF from a 2017 meta-analysis²² (the same as that used in HAPINZ3.0) which estimated an ERF of 1.05 per 4µg/m³. In any case, a p value of 0.071 does not mean the result is incorrect, only that there is a slightly higher chance (1 in 14) that the result from the stated methodology was due to chance, compared with the 1 in 20 chance (p=0.05) usually set as the acceptable threshold in epidemiological research.

Appliance input data

The model uses data from the 2023 Census to estimate how many wood burners, pellet burners and unflued gas heaters are in use in households in New Zealand. Note the Census question refers to the “main forms of heating” used in the household – a respondent can choose multiple “main forms”, and some houses may use both wood burning and unflued gas heating. It also does not count the number of appliances i.e. a household may use multiple unflued gas heaters or woodburners across different areas of the house. The model assumes only one heating type and one appliance per household, which may lead to an erroneous estimate of the total health harms occurring – some households may be experiencing additive health harms from multiple appliances, while others may only occasionally use gas or woodburners and mainly employ electric heating in the home.

The Economic and Fiscal Costs Model

The main function of the economic and fiscal costs component of the overall modelling exercise is to assign costs that accompany the estimated health harms, divided into

¹⁹ Hales S, Atkinson J, Metcalfe J, Kuschel G, Woodward A. Long term exposure to air pollution, mortality and morbidity in New Zealand: cohort study. *Science of The Total Environment*. 2021 Dec 20;801:149660.

²⁰ Huangfu P, Atkinson R. Long-term exposure to NO₂ and O₃ and all-cause and respiratory mortality: A systematic review and meta-analysis. *Environment international*. 2020 Nov 1;144:105998.

²¹ <https://environment.govt.nz/assets/publications/HAPINZ/HAPINZ-3.0-Detailed-methodology.pdf>

²² Khreis H et al (2017). Exposure to traffic-related air pollution and risk of development of childhood asthma: A systematic review and meta-analysis. *Environment International* 100: 1-31.

direct costs to government (fiscal costs, generally incurred through provision of health services), and costs to society including those that fall on the individuals experiencing the health impact (economic costs, the greatest contribution of which come from premature death and restricted activity days).

Assessment

Value of Statistical Life

One of the main contributors to the high economic costs estimated in this project is the change in the Value of a Statistical Life (VoSL) figure, from \$4,527,300 in 2019 to \$12,500,500 in 2021. This methodological change is appropriate and in line with Treasury's current approach. The authors have updated the HAPINZ per-tonne damage costs to use as an input to calculating the economic costs of *indoor* appliance use resulting in *outdoor* pollution.

It should be noted that this difference in VoSL does make comparison with the HAPINZ3.0 report complicated. That report estimated social costs of \$15.6 billion attributable to outdoor PM2.5 and NO2 exposure (some of which is caused by the appliances considered in the Indoor Combustion report, much of which is caused by transport emissions), while the indoor pollution burden is estimated at \$5.8 billion. In future, an updated HAPINZ analysis using recent VoSL figures would provide a more helpful point of comparison to judge the relative contributions of indoor and outdoor air pollution nationally.

Cost choices

For simplicity's sake, the costs assigned to each of the 8 health outcomes modelled are either fiscal **or** economic. It should be noted that each outcome has both fiscal and non-fiscal costs e.g. a hospitalisation for a cardiovascular disease event in an adult has significant costs to the individual and their whānau/carers. Illness in children has economic impacts for parents/carers who in many cases must take time from employment, and chronic illness in children affects education and subsequent income. These impacts would be difficult to model and it is reasonable that they have been simplified out, but this is another example of where the model outputs represent lower bounds of true costs.

The fiscal cost per asthma case is based on the HAPINZ3.0 calculation, which assumes one additional GP visit and the population average of asthma-related pharmaceutical costs applies to each child under 18. This seems somewhat low, given generally prescriptions require some input from a doctor at least once every 3 months – potentially more often for severe cases or where first-line therapy is not adequately controlling symptoms. It would be worth re-visiting the methods for this calculation as it may be an underestimate. Asthma cases and hospitalisations in children could also be

reasonably expected to incur some economic costs related to caregivers taking time off work – these might outstrip the direct fiscal costs related to providing medical treatment for illness.

Results – validity and presentation

Overall results

The results of the Indoor Combustion report are a reasonable estimate of a limited range of health harms and associated economic costs. As discussed above, the harms of air pollution extend beyond the set of outcomes modelled – it should be emphasised in any dissemination of this report’s findings that the estimates presented are essentially a minimum “floor” for health harms and costs associated with indoor air pollution. As the report highlights, even taking the “low” scenario values results in “appreciable” health impacts and economic costs.

The costs per appliance table accurately reflects the modelling exercise that has taken place, and it is a reasonable and valid estimate. Kashtan 2024 undertook a similar calculation and arrived at a figure of \$4500USD per year per household with a gas or propane stove – this is similar to the \$9415NZD figure estimated in the report. The Delgado-Saborit report estimates total economic costs of 160 billion Euro from premature deaths and 4 billion Euro from asthma across the EU and UK attributable to gas stoves – about 325 Euro per person (based on 66.8 million people in the UK and 440 million in the EU at the time the research considered). The Indoor Combustion report’s estimate for economic costs attributable to gas stoves is \$3.308 billion NZD, which translates to approximately \$633NZD per person (using a 2025 population of 5.22 million) – this is remarkably similar to the EU/UK estimate which would be \$594 per person at Oct 2024 exchange rate.

Population Attribution

In epidemiology, a useful approach to contextualise the impact of a certain hazard or exposure is the calculation of population attributable fractions (PAF). A PAF represents the total proportion of health impact that occurs due to exposure to, in this case, the use of an indoor combustion appliance. Put another way, it is the proportion of health impact (and cost) that would disappear once use of the appliance was discontinued (accounting for lag effects in this case). For instance, there were 78,853 respiratory hospitalisations in New Zealand in 2022²³ – if this number had stayed constant through to 2025, then the results of this report suggest that 1.5% of all respiratory hospitalisations (1,177 across the three appliance types) are attributable to just the

²³ Telfar Barnard L, Zhang J. The impact of respiratory disease in New Zealand: 2020 update. Asthma and Respiratory Foundation NZ: Wellington, New Zealand. 2021.

indoor pollution impacts of these three appliances - the outdoor pollution contributions are additional.

Another example is asthma prevalence – the 2023/24 New Zealand Health Survey estimates 99,000 children 2-14 have “medicated asthma”,²⁴ and the report itself estimates a 0-18 years prevalence of 152,169 in 2016 based on HAPINZ data. The report estimates there are 3,230 cases attributable to indoor air pollution from gas stoves and unflued gas heaters – while this age range is up to age 17 so the figures are not directly comparable to the NZHS, the PAF is perhaps between 2% (HAPINZ denominator) to 3% (rough estimate of NZHS denominator) of the total paediatric asthma burden in New Zealand. The report would benefit from adding these calculations for its findings to contextualise the disease burden.

International Comparison

Related to the above points on PAFs, the report would be improved by discussing its findings in the context of similar work internationally. The Knibbs (2018) study conducted in Australia estimated a PAF of 12.3% for gas stoves’ contribution to childhood asthma prevalence, the Gruenwald (2022) study estimated 12.7%²⁵ and the Kashtan (2024) study estimated 3.8% (confidence intervals in Gruenwald and Kashtan overlap) in the USA, and the Delgado-Saborit (2024) study estimated 8.46% across the EU and UK. In the context of these figures, it would be helpful for the report to discuss why its estimates appear to be lower than some other estimates (though perhaps comparable to the Kashtan study). PAFs may differ from country to country due to variations in prevalence of exposure to the hazard, or differences in contributors of other risk factors. For example, the liver cancer PAF for alcohol might be lower in countries with very high Hepatitis B and C virus prevalence, as these infections are responsible for a greater proportion of cases.

The prevalence of gas stoves in the USA is 38%²⁶, and the Delgado-Saborit report uses a prevalence of 32% across the EU, which is not dissimilar enough from the 24% estimated in the Indoor Combustion report to explain the magnitude of difference in asthma PAF estimate from the three studies reporting PAFs between 8-13%, acknowledging the Kashtan study is much closer. To explain this difference, there must either be other major risk factors for asthma present in New Zealand that are not

²⁴ Ministry of Health. 2024. Annual Data Explorer 2023/24: New Zealand Health Survey [Data File]. URL: <https://minhealthnz.shinyapps.io/nz-health-survey-2023-24-annual-data-explorer/>

²⁵ Gruenwald T, Seals BA, Knibbs LD, Hosgood HD. Population attributable fraction of gas stoves and childhood asthma in the United States. *International Journal of Environmental Research and Public Health*. 2023 Jan;20(1):75.

²⁶ United States Energy Information Administration. 2023. <https://www.eia.gov/consumption/residential/data/2020/>

present in other countries, or the report's results should be recognised as a low outlier estimate in the international context.

Recommendations for further work

Equity

Future research or additional work within the same model should focus on the equity impacts of indoor combustion appliance use. The Census data on household heating methods can be disaggregated by variables such as ethnicity, socioeconomic status and rurality which have important policy implications. The estimate for gas stoves from Rewiring Aotearoa does not have this information, but other surveys such as those commissioned by EECA could be designed to serve this purpose. The existing model could potentially be modified to disaggregate households by area-level socioeconomic status and rurality. Ethnicity may be more complicated to disaggregate as various members of a household may have different ethnic identities – a linkage study at the individual-to-household level would be required.

Expanding the range of health impacts

As discussed above, while the HAPINZ3.0 report and the Indoor Combustion report cover an important set of health and healthcare utilisation outcomes, and this is a reasonable prioritisation, there are many more outcomes that could be incorporated into the model. Estimates of relative risk per increment of exposure are available for many of these outcomes, and expanding the range would strengthen the case for policy interventions, as well as provide information for patients, non-government organisations and government about specific conditions.

Taking lung cancer as an example, a major meta-analysis published in 2020 reports an ERF for lung cancer of 1.13 per 10µg/m³ of PM_{2.5}²⁷. Lung cancer is the single greatest cause of cancer mortality in New Zealand, with particularly high rates for Māori.²⁸ These deaths will be captured by the premature mortality measure employed in the report, but it would be worthwhile calculating specific causes of mortality like lung cancer to inform health programmes and policy – for example, lung cancer screening is proposed to be based on smoking history, but there may be a case for air pollution exposure to be included as a criteria.

²⁷ Turner MC, Andersen ZJ, Baccarelli A, Diver WR, Gapstur SM, Pope III CA, Prada D, Samet J, Thurston G, Cohen A. Outdoor air pollution and cancer: An overview of the current evidence and public health recommendations. *CA: a cancer journal for clinicians*. 2020 Nov;70(6):460-79.

²⁸ <https://teaho.govt.nz/index.php/reports-and-numbers/cancer-deaths>