The imputation of health outcomes from the domestic use of gas in the EECA report

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Introduction

The Energy Efficiency and Conservation Authority (EECA) of New Zealand commissioned Emission Impossible Limited and Resource Economics to produce a health impact assessment (HIA) of the health effects and costs of indoor combustion. The review, titled "Indoor Combustion in New Zealand Homes: Health Effects and Costs" was published in September 2025 and is referred to herein as "the report".

The report attempts to replicate parts of the major HIA on this topic for the United Kingdom and European Union (Delgado-Saborit *et al* 2024) and apply it to New Zealand. The domestic use of gas was one of the components of indoor combustion used in the health impact assessment. The imputed estimate of adverse health outcomes from domestic gas use was a focus of the report.

Environmental health impact assessments typically involve considerable uncertainty due to complex relationships between environmental exposures and health. They often do not explore the uncertainty of the model used (Mesa-Frias et al 2013a). It is necessary to critically appraise the methods used to quantify the uncertainty in environmental health impact assessments.

A fundamental requirement of a health impact assessment, like the report, is the existence of a causal relationship between environmental exposures and health outcomes (Mesa-Frias et al 2013b). Thus, the fundamental question is: Does the use of domestic gas cause illness, and if it does, which illnesses and to what degree?

The domestic gases used in New Zealand are, in roughly equal proportions: bottled liquid petroleum gas (LPG), a mixture of propane and butane; and, natural gas, which is predominantly methane and only available for domestic use in the North Island. The gases are primarily used for household heating and cooking; with very similar numbers of households using each gas.

Nitrogen dioxide (NO_2) is a primary respiratory irritant. NO_2 is not very water-soluble relative to other commonly respired gases and may cause inflammation in the lower respiratory tract. It may also stimulate immunological reactions in the lower respiratory tract.

The scientific assessment of the effects of an exposure on illness

The scientific assessment of the effects of an exposure on illness in the population is called medical epidemiology. Epidemiology involves the design, conduct, analysis, and interpretation of scientific studies of the determinants of disease. It is necessary for the assessment of hypotheses, such as the claim that domestic use of gas causes illness.

The different types of epidemiological studies are ranked according to scientific value. That is, there is a hierarchy of scientific value for the study designs used. They are from levels 1 to 4 (high to low):

1. experimental studies such as randomised controlled trials;
2. observational cohort studies;
3. observational case-control studies; and,
4. some observational surveys investigating features of exposed and non-exposed population groups.

Descriptive studies, which describe the exposure or disease separately, are not analytical studies of the relationship between exposure and disease. However, they can generate hypotheses that require exploration by analytical studies.

Meta-analyses are sometimes considered to be the highest-ranked studies, but ranking depends on the types of studies included in the analysis. For example, a meta-analysis of case-control studies would not be of more intrinsically scientific value than a well-conducted randomised controlled trial. When there is considerable heterogeneity in the results of different studies, it is not considered appropriate to conduct a quantitative meta-analysis because that would misrepresent the association between exposure and disease.

In addition, researchers conducting meta-analyses seldom have control over the data collection in the research studies that contribute. Despite the ranking of study designs, a poorly conducted study, or one with a low response rate, would be considered to have low scientific value.

Does domestic gas use in New Zealand cause illness?
Studies of causation need to involve appropriate comparisons, appropriate timing or follow-up, appropriate specification of the exposure and illness, and appropriate measurement of the exposure (Holland et al 1991).

In addition, associations between an exposure and illness are not necessarily causal and stringent criteria, such as the commonly used Bradford-Hill criteria, need to be met before claiming an exposure is the cause of illness.

In the report, the effect of domestic gas use on asthma and health service hospitalisation was imputed in two separate stages. Firstly, health outcomes putatively related to NO_2 exposure were chosen. A measure of their occurrence was also chosen.

An observational study of geographic environmental outdoor pollution and nationally recorded health outcomes, such as premature mortality, cardiovascular and respiratory hospitalisations, and hospital admissions for asthma in New Zealand (Kuschel *et al* 2022) was reviewed and assisted in the choice of health outcomes used in the report.

Second, estimates of chronic NO_2 exposure were imputed from modelling. These were then linked to impute the level of potential premature mortality, cardiovascular and respiratory hospitalisations, and hospital admissions for asthma in New Zealand caused by NO_2 exposure from the use of domestic gas. Direct assessment of a relationship between chronic domestic NO_2 exposure in New Zealand and illness was not conducted.

The authors listed 3 key references regarding the health effects of gas stoves. They were:

- i Delgado-Saborit *et al* (2024). *Assessment of the health impacts and costs associated with indoor nitrogen dioxide exposure related to gas cooking in the European Union and the United Kingdom*.
- ii Kashtan *et al* (2024). *Nitrogen dioxide exposure, health outcomes, and associated demographic disparities due to gas and propane combustion by U.S. stoves*.
- iii Puzzolo *et al* (2024). *Estimated health effects from domestic use of gaseous fuels for cooking and heating in high-income, middle-income, and low-income countries: a systematic review and meta-analyses.*

The article of Puzzolo *et al* (2024) was used to estimate the effects of NO_2 exposure on the health outcomes of interest. This study was a meta-analysis of numerous studies worldwide. There were large variations in the reported associations between illness and the use of gaseous fuels among the large number of studies included.

Unfortunately, many of the studies included were cross-sectional studies, which are of limited value in the assessment of causation. When the meta-analysis analysis was restricted to higher-quality studies there was no statistically significant relationship between gas use and pneumonia or chronic obstructive pulmonary disease.

This systematic review was used by the authors of the EECA report to determine what illnesses or health outcomes to include in their analysis. However, it did not find a statistically significant association between gas use and childhood asthma, adult asthma, wheeze, cough and breathlessness. Despite this, the authors of the EECA report considered these illnesses and symptoms to be caused by the domestic use of gas.

The illnesses postulated to be caused by domestic gas use in New Zealand in the report were:

1. Premature mortality for all adults (30+ years) or years of life lost for all adults (30+ years)
2. Cardiovascular hospitalisation for all ages
3. Respiratory hospitalisation for all ages
4. Asthma/wheeze hospitalisations (0-18 years)
5. Incidence of paediatric asthma (0-18 years)

The publications (Kashtan et al 2004, Delgado-Saborit et al 2024, Bennitt et al 2021) cited by the authors to support their choice of health outcomes in the report estimated risks of disease rather than hospitalisation from a broad group of diseases.

Cardiac or respiratory hospitalisations are health service outcomes and are not direct health outcomes or diagnoses of disease. They can be the potentially costly manifestations of disease, but many hospitalisations are at the discretion of the health providers.

The willingness of doctors to diagnose respiratory illnesses such as asthma and their predilection to admit patients to hospital varies considerably among doctors, and the availability of hospital beds for admissions. Whether this is associated with the domestic use of gas is unknown and may confound any putative association between domestic gas use and hospitalisations for respiratory or cardiac disease.

In addition, some people may be hospitalised several times for the same illness, while others are only admitted once, but the frequency of personal admission does not appear to have been adequately considered in the report.

Outcomes such as cardiac or respiratory hospitalisation include a very wide range of diseases, some of which are genetic and often related to chronic cigarette smoking. For example, respiratory admission also occurs for conditions such as pulmonary embolus, spontaneous pneumothorax, and chest injuries, which are unlikely to be caused by domestic gas use. In addition, cigarette smoking and the amount smoked over time is a well-known risk factor for many cardiac and respiratory illnesses.

This exposure, and passive exposure to cigarette smoke, may be more or less likely among people living in households with domestic use of gas in New Zealand. Therefore, the assessment of cardiac or respiratory hospitalisation requires precise adjustment for personal, and passive, smoking exposure. The application of putative risks for specific diseases to a whole group of diseases is inappropriate, greatly inflates any cost estimates of the possible effects of domestic gas use, and is likely to produce very misleading results.

In the analysis of children in the HAPINZ 3.0 study, educational and smoking status data were not available (Kuschel *et al* 2022). Therefore, the justification from the HAPINZ 3.0 study for the inclusion of respiratory disease in those 0-18 years of age in the report is not clear.

In addition, after review of a previous meta-analysis (Lin et al 2013) used by the authors of the report and the inclusion of more published studies, a meta-analysis of gas cooking and asthma in children did not consider the evidence supported causality (Li et al 2023). This was due to the large heterogeneity (lack of consistency) in the results of the studies examined (p24, Delgado-Saborit *et al* 2024). Thus, the inclusion of the "incidence" of asthma in children as a health outcome does not appear to be justified.

The term asthma can be used for both the disease and attacks of the disease which may, or may not, result in hospitalisation. In addition, the authors of the report appear to use the term incidence of asthma to describe the frequency of admissions to hospital for asthma or wheeze (Table 2, page 19) and not the incidence of asthma (number of people newly diagnosed with asthma). Thus, despite the labelling of the authors, the impact of domestic gas use on the incidence of asthma was not assessed.

Estimation of New Zealand NO_2 exposure

The outdoor concentration of NO_2 varies considerably and vehicular traffic is the major contributor. The report did not consider interior NO_2 levels to be influenced by exterior NO_2 concentrations.

This contradicts the major European assessment of gas cooking (Delgado-Saborit et al 2024, p 11) which stated the indoor to outdoor ratio of NO_2 varies by building type, season and region, yet the authors of the report, despite using Delgado-Saborit et al 2024 as a major reference, say their own literature review found no correlation between indoor and outdoor air pollution by NO_2.

No explanation of this discrepancy appears to be given. This is important because the authors of the report used household NO_2 concentrations measured in urban areas with high outdoor pollution levels in New Zealand to impute possible average household NO_2 exposure for all New Zealand. Thus, the estimates of overall NO_2 exposure are very likely to be inflated.

Only one study was used to estimate NO_2 exposure in New Zealand households (Gillespie-Bennett *et al*, 2008). This was a study of households with a child 6-12 years of age with asthma diagnosed by a doctor in Bluff, Dunedin, Christchurch, Porirua, and the Hutt Valley regions of New Zealand at the end of winter.

The outdoor NO_2 exposure in Porirua and the Hutt Valley have been found to be higher than most other regions of the greater Wellington region (Greater Wellington Regional Council 2009). Traffic in Dunedin, Christchurch, Porirua, and the Hutt Valley can be expected to produce higher than national average outdoor levels of NO_2. This can be expected to have influenced the domestic measurements used in the report.

In addition, the choice of households for the measurements of domestic NO_2 concentrations used in the report cannot be considered equivalent to rural households or households elsewhere in New Zealand. Residents of the households were approached to allow the measurement of NO_2 exposure in the living room and the child's bedroom.

Baseline 4-week measurement of NO_2 concentrations were sought from 462 households of which 422 (91.3%) consented and provided at least some of the baseline measurements. These measurements were used in the report to impute New Zealand annual domestic NO_2 exposure. However, if NO_2 exposure induced some of the asthma in childhood, these households would be expected to have higher NO_2 concentrations than the national average.

Thus, these very specific households in areas of high vehicular traffic are not a random selection of households in New Zealand, so the results do not represent average household NO_2 exposure.

Within this survey of specific households, a randomised controlled trial of the effect on measured NO_2 concentrations in the living room and child's bedroom from replacing unflued mains gas or LPG heaters with electric heat pumps was conducted (Gillespie-Bennett *et al* 2008). Of the 409 households randomised for the trial, 200 were allocated to the intervention arm of which 175 households (87.5%) participated by returning usable data, as did 174 (83.3%) of the 209 control households.

An assessment of potential selection bias from non-participation in the two groups was not reported and the analysis only compared NO_2 measurements of participating households rather than all the households randomised to these groups. An analysis of all households randomised, participating or not, was not presented.

Accepted criteria required of studies for exposure to cause of illness

- Temporality: Of all the criteria, this is the most widely accepted requirement of a causal relationship.

  There appear to have been few follow-up studies of people exposed to the use of domestic gas and the subsequent development of illness. No scientific results of the length of time of exposure before illness may have developed were presented.

- Strength of association: A stronger relationship between the exposure and outcome implies a higher likelihood of causality. A relationship's strength is typically measured by statistical analysis.

  There are at least two relevant measures of domestic gas use. First, what is the critical acute level of gas use that precipitates acute illness. Second, what average level of chronic gas use, and over what duration, is required before it produces long-term illness. Neither of these were reviewed in the report.

- Consistency: Similar relationships between the exposure and outcome are observed in different studies and settings.

  The development of health outcomes was imputed from studies that measured indoor NO_2. There were considerable variations in the measured levels of NO_2. Little direct measurement of illness after exposure was included in the analysis. No similar imputation results were provided.

- Specificity: An exposure is linked to a specific outcome in a particular population.
  The report focused on premature mortality, cardiovascular and respiratory hospitalisations. These are not specific to a particular disease. The specific evidence presented that NO_2 exposure causes cardiovascular and respiratory disease appears weak.

- Biological relationship: An increased level of exposure results in an increased frequency of the effect, also known as the dose-response relationship.

There are instances when this criterion is not appropriate. For example, asthma can be triggered by very low levels of exposure to an allergen; however, the proposed effect of NO_2 on the development of asthma does not involve NO_2 being a direct allergen. There appear to be few studies that have assessed the frequency of illnesses after exposure to specific levels of NO_2.

- Plausibility: The proposed exposure-outcome relationship is consistent with biological knowledge.

- A primary respiratory irritant from the combustion of gas is NO_2 which, relative to other commonly respired gases, is not as water soluble and is thought to create inflammation or enhance immunological reactions of the lower respiratory tract. A relationship between domestic NO_2 exposure and LPG use at home is plausible.

- Coherence: New evidence aligns with existing findings.
  New evidence has not decreased the variability of associations between illness and domestic measurements of NO_2 concentrations.

- Experiment: Experimental studies support the presumed causal relationship.
  The results have been variable but the association of domestic NO_2 concentrations and illness was lower in experimental studies (Puzzolo et al 2024).

- Analogy: A known causal relationship between an exposure and outcome suggests a similar relationship for another exposure and outcome.
  Numerous gases, and fumes can cause human respiratory illness.

Conclusion

The report prepared by Emission Impossible Limited and Resource Economics to review the health effects and costs of indoor gas combustion for the EECA used coarse modelling of New Zealand domestic NO_2 exposure to impute levels of respiratory and cardiovascular hospitalisations, as well as hospitalisations for asthma.

The use of estimates of specific respiratory diseases (in particular, chronic obstructive pulmonary disease and pneumonia) appear to have been used to impute the risk of cardiac and respiratory hospitalisation.

In addition, the authors have used the term "incidence of asthma" (the number of new cases in the population) when the prevalence of hospital admissions for asthma appears to have been used (the number of hospital admissions for asthma attacks occurring in the population).

There are many respiratory and cardiovascular diseases and gas use cannot be expected to influence the multitude of diseases included in the broad collection of diseases and severity requiring hospitalisation. This lack of specificity does not suggest a causal relationship. Asthma was the only specific disease included in the HIA of the report, but only the rate of hospitalisations for asthma or wheeze was included, and reasons for hospitalisation with these conditions can vary considerably.

Imputations are only as good as the accuracy of the assumptions used. Analogy from research of the households of other countries was offered as validation of some of the assumptions, but other assumptions appear closer to guesswork. All the assumptions need to be correct for the results to be useful. It is not appropriate to consider that if most of the assumptions are correct, then the results are approximately correct, as one erroneous assumption can greatly influence the results of such models (Mesa-Frias et al 2013a).

The report lacks specific measurement of domestic gas use over time in such a way that temporal relationships between exposure and illness in New Zealand conditions can be determined with any confidence. Choosing upper and lower values for each important, but imputed, parameter in the model of the report does not capture the interaction with other variables when a single parameter is altered.

This is a major issue in environmental health impact assessments (Mesa-Frias et al 2013a), such as the report. Since a health impact assessment requires the existence of a causal relationship between environmental exposures and health outcomes (Mesa-Frias et al 2013b), and the report does not evaluate or establish causation in the New Zealand domestic environment, the imputed results in the report can be considered to be inaccurate and misleading.

The report does not provide a basis for sound policy development regarding the domestic use of gas and health outcomes in New Zealand.

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Addendum

Public Health Research and Consulting Services is a partnership between Dr Brian Cox and Dr Mary Jane Sneyd that designs, conducts, reviews, and publishes public health research. It provides reports that assess the public health risks of exposures and activities. Over the past 30 years, Drs Cox and Sneyd have designed, conducted, analysed, and reported public health research and health evaluations for the World Health Organization, the National Institutes of Health (USA), the International Agency for Research on Cancer, regional public health services, and other organisations in New Zealand.

Dr Sneyd has degrees in biochemistry, physiology, medicine and has a PhD in epidemiology. Dr Cox has degrees in mathematics and medicine, a PhD in epidemiology, and is a specialist in public health medicine.

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