Cooking fuels and prevalence of asthma: a global analysis of phase three of the International Study of Asthma and Allergies in Childhood (ISAAC)

*Gary W K Wong, Bert Brunekreef, Philippa Ellwood, H Ross Anderson, M Innes Asher, Julian Crane, Christopher K W Lai, for the ISAAC Phase Three Study Group**

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See Comment page 351

*Members listed in the appendix

Department of Paediatrics and School of Public Health (Prof G W K Wong MD), and Department of Medicine and Therapeutics (Prof C K W Lai DM), Chinese University of Hong Kong, Prince of Wales Hospital, Hong Kong SAR, China; Institute for Risk Assessment Sciences and Julius Centre for Health Sciences and Primary Care, University Medical Centre Universiteit Utrecht, Utrecht, Netherlands (Prof B Brunekreef PhD); Department of Paediatrics: Child and Youth Health, University of Auckland, Auckland, New Zealand (P Ellwood MPH, Prof M I Asher MBChB); MRC-HPA Centre for Environment and Health, Division of Public Health Sciences and Education, St George's, University of London, London, UK (Prof H R Anderson MD); and Wellington Asthma Research Group, Department of Medicine, University of Otago, Wellington, New Zealand (Prof J Crane MBBS)

Correspondence to: Prof Gary WK Wong, Department of Paediatrics, Prince of Wales Hospital, Chinese University of Hong Kong, Shatin, Hong Kong, China
wingkinwong@cuhk.edu.hk

See Online for appendix

Summary

Background Indoor air pollution from a range of household cooking fuels has been implicated in the development and exacerbation of respiratory diseases. In both rich and poor countries, the effects of cooking fuels on asthma and allergies in childhood are unclear. We investigated the association between asthma and the use of a range of cooking fuels around the world.

Methods For phase three of the International Study of Asthma and Allergies in Childhood (ISAAC), written questionnaires were self-completed at school by secondary school students aged 13–14 years, 244 734 (78%) of whom were then shown a video questionnaire on wheezing symptoms. Parents of children aged 6–7 years completed the written questionnaire at home. We investigated the association between types of cooking fuels and symptoms of asthma using logistic regression. Adjustments were made for sex, region of the world, language, gross national income, maternal education, parental smoking, and six other subject-specific covariates. The ISAAC study is now closed, but researchers can continue to use the instruments for further research.

Findings Data were collected between 1999 and 2004. 512 707 primary and secondary school children from 108 centres in 47 countries were included in the analysis. The use of an open fire for cooking was associated with an increased risk of symptoms of asthma and reported asthma in both children aged 6–7 years (odds ratio [OR] for wheeze in the past year, 1·78, 95% CI 1·51–2·10) and those aged 13–14 years (OR 1·20, 95% CI 1·06–1·37). In the final multivariate analyses, ORs for wheeze in the past year and the use of solely an open fire for cooking were 2·17 (95% CI 1·64–2·87) for children aged 6–7 years and 1·35 (1·11–1·64) for children aged 13–14 years. Odds ratios for wheeze in the past year and the use of open fire in combination with other fuels for cooking were 1·51 (1·25–1·81 for children aged 6–7 years and 1·35 (1·15–1·58) for those aged 13–14 years. In both age groups, we detected no evidence of an association between the use of gas as a cooking fuel and either asthma symptoms or asthma diagnosis.

Interpretation The use of open fires for cooking is associated with an increased risk of symptoms of asthma and of asthma diagnosis in children. Because a large percentage of the world population uses open fires for cooking, this method of cooking might be an important modifiable risk factor if the association is proven to be causal.

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Introduction

Despite much research, little is known about the cause of asthma. The international study of asthma and allergies in childhood (ISAAC) has documented a wide variation in asthma prevalence across the world and has also detected evidence of a continuing increase, especially in low-income and middle-income countries.[1,2] The possible role of air pollution in the development of respiratory diseases is a major focus of research. Several studies have investigated the association between indoor air pollution and asthma and chronic obstructive pulmonary disorder (COPD).[3,4] In high-income countries, the use of gas appliances for cooking has been implicated as a cause of respiratory symptoms, particularly in women.[5] The use of gas as cooking fuel has also been implicated as one of the factors that might explain the higher asthma prevalence in Chinese children in Hong Kong compared with children in other Chinese cities.[6] However, results from the European community respiratory health survey of more than 10 000 respondents did not show any relation between the use of gas for cooking and obstructive respiratory symptoms.[7]

Exposures to domestic fire burning of coal and biomass such as wood, animal dung, and crop residues for cooking or heating are widespread, especially in rural areas of poor countries. According to WHO, at least half

the world's population live in households in which solid fuels or biomass are the primary fuel for cooking, heating, or both.[8,9] In resource-poor countries, cooking with biomass is typically done on unvented stoves without any form of ventilation system.[10] In India, biomass burning has been shown to be associated with increased respiratory symptoms in children.[11] A nationwide study in India showed that exposure to the combustion of biomass and solid fuels was associated with an increased risk of asthma in women.[12] A study of 508 adults in the USA also showed a positive association between asthma and exposure to cooking indoors with wood and coal.[13] WHO estimated that indoor air pollution from the burning of biomass causes almost 2 million deaths annually.[8] Because the burning of biomass fuel or the use of gas for cooking are potentially modifiable factors, the study of their relation with asthma and wheezing illnesses in children is important.

Many studies of the association between cooking fuel and asthma have been of low statistical power. Furthermore, estimation of the individual exposure presents a major challenge because the proximity to the sources of exposure, the duration of exposure, and accurate assessment of ventilation are not easily quantifiable in large studies. The existing evidence about the association between household air pollution from biomass burning and asthma is conflicting, with more consistent positive associations in children than in adults.[14–18] We investigated the relation between asthma and the use of a range of cooking fuels in study centres around the world. Using standardised methods, phase one of ISAAC documented large variations in asthma prevalence across the world. Phase two included objective measurements including skin-prick test and bronchial challenge test, providing further support of the importance of environmental factors in the development of asthma. The results reported here are based on a detailed environmental questionnaire administered to children in 47 countries to test different cause hypotheses of asthma as part of the phase three ISAAC study.

Methods

Study design

ISAAC phase three is an expansion using the same study design of the first phase of ISAAC, findings from which showed a wide variation in the prevalence of childhood asthma and related atopic disorders across the world.[1,2,19] The details of the study protocol are available elsewhere.[2,19] Briefly, written questionnaires were self-completed at school by secondary school students aged 13–14 years who were then, in most centres, shown a video questionnaire on wheezing symptoms. 244 734 (78%) adolescents completed a video questionnaire on wheezing symptoms. Parents of children aged 6–7 years completed the written questionnaire at home. School children in these two targeted age groups were randomly selected by individual centres from within a defined geographical area. Studies were done with local ethics approval and the method of consent was determined by local ethics committees.[20] The ISAAC International Data Centre in Auckland, New Zealand, assessed the submitted data for adherence to the standardised ISAAC protocol. In this Article, we focus on "current wheeze" (in response to the question "Have you (has your child) had wheezing or whistling in the chest in the past 12 months?"), "asthma ever" ("Have you (has your child) ever had asthma?"), symptoms of "rhinoconjunctivitis" ("In the past 12 months, have you (has your child) had a problem with sneezing, or a runny, or blocked nose when you (he/she) did not have a cold or the flu?" and "In the past 12 months, has this nose problem been accompanied by itchy-watery eyes?"), and symptoms of "eczema" ("Have you (has your child) had this itchy rash at any time in the past 12 months?" and "Has this itchy rash at any time affected any of the following places: the folds of the elbows, behind the knees, in front of the ankles, under the buttocks, or around the neck, ears or eyes?"). These questions related to eczema were preceded by the question "Have you (has your child) ever had an itchy rash coming and going for at least 6 months?"; if

For the **core and environmental questionnaires** see http://isaac.auckland.ac.nz/

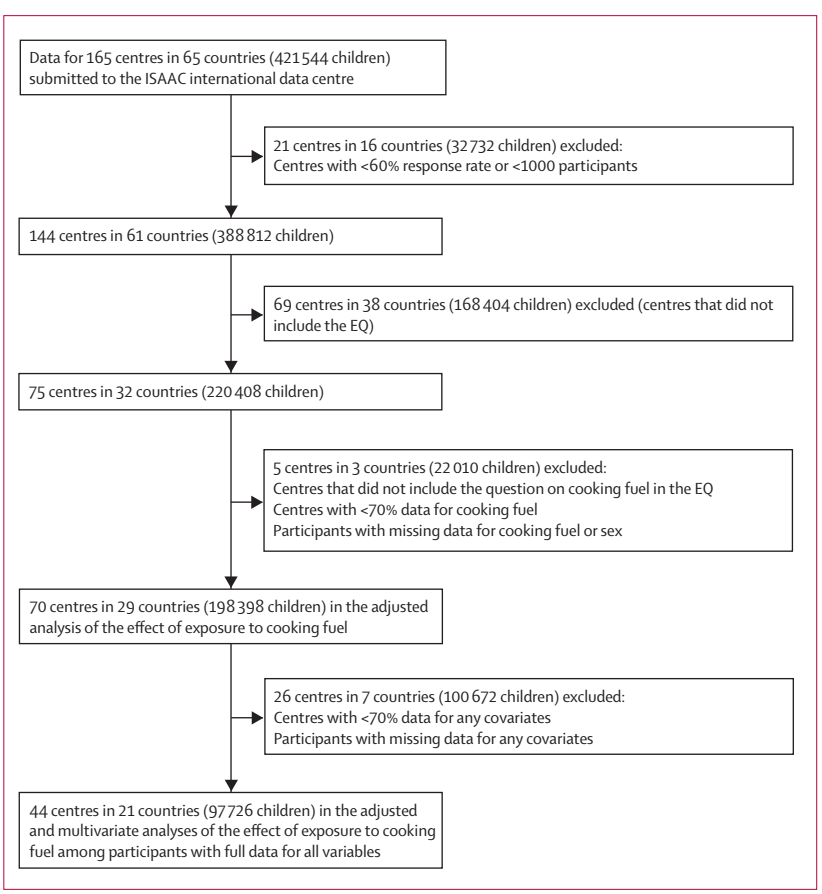

Figure 1: **Trial profile for children aged 6–7 years**
EQ=environmental questionnaire.

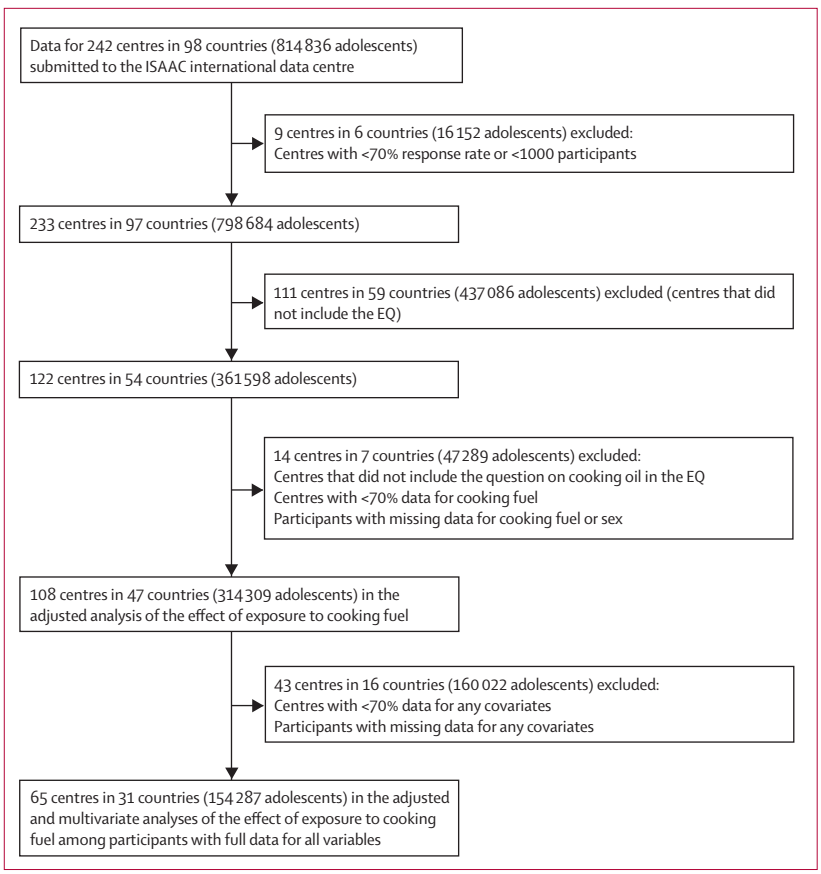

Figure 2: **Trial profile for children aged 13–14 years**
EQ=environmental questionnaire.

the answer to this question was negative, the following questions about eczema were not asked. We analysed "symptoms of severe asthma", defined as children with current wheeze who, according to the written questionnaire, in the past 12 months had four or more attacks of wheeze, or one or more nights of sleep disturbance from wheeze per week, or wheeze that was severe enough to limit the child's speech to only one or two words at a time between breaths. Previous ISAAC analyses showed that a combination of these characteristics of more severe wheezing episodes was more closely associated with asthma mortality and hospital admissions than current wheeze alone.[21] Additionally, children aged 13–14 years were asked to respond to a video questionnaire showing various symptoms of wheeze in children of similar age, and a positive response to the question relating to a scene showing a young person wheezing at rest ("Has your breathing ever been like this in the past 12 months?") was defined as "current wheeze–video".[22]

In ISAAC phase three, an optional environmental questionnaire (dependent on the resources available at each centre) was administered in addition to the core symptom questionnaire to assess several specific cause hypotheses.[19] One of the questions in the environmental questionnaire that we analysed in the present study was "What fuel is usually used for cooking in your house?" The four answers to choose from were "electricity", "gas", "open fires", and "other" (if respondents chose other, they had to specify which fuel they used). Respondents could choose more than one category. For this analysis, we used "electricity" as the reference group, and compared it with the other categories, including "gas", "open fires only", "open fire in combination with other fuel", "multiple non-fire fuel", and "other fuel only". The group of "other fuel" is small but heterogeneous, including the use of microwave, solar power, kerosene, liquid petroleum gas, and methane.

Statistical analysis

We calculated odds ratios (ORs) using generalised linear mixed models for a binomial distribution and logit link and with the centres modelled as a random effect. In the initial analyses of associations between outcomes and use of different types of cooking fuel, all children from centres with submission of cooking fuel data were included with adjustment for sex, region of the world, language, and gross national income. Regions of the world were Africa, Asia-Pacific, Eastern Mediterranean, Latin America, North America, northern and eastern Europe, Oceania, the Indian subcontinent, and western Europe. The written questionnaire was translated from English, according to the standardised ISAAC phase three protocol, into local languages: including Arabic, Chinese, English, Hindi, Indonesian, Portuguese, and Spanish.[24] Centres were allocated to four categories of socioeconomic status based on their country's gross national income per person: low, lower-middle, upper-middle, and high, as categorised by World Bank gross national income data.[25] To define affluent and non-affluent status, we combined the lower three categories as the non-affluent countries and the top category as the affluent countries. In the final models, we did multivariate analyses, adjusting for other covariates in the environmental questionnaire, including maternal education, maternal and paternal smoking, television watching, exercise, siblings (older and younger), consumption of fast food, frequency of truck traffic, and paracetamol use. We included these factors because they were known to be associated with respiratory symptoms or have been shown by our previous studies to be associated with wheeze and asthma.[26,27] We tested the effect modification by sex and by affluence by comparing the log-transformed ORs for boys and girls, and for affluent and non-affluent study centres. The log-odds-ratio for interaction was derived as the difference between the stratum-specific log-odds-ratios, and its variance was estimated as the sum of the variances of each of the stratum-specific log-odds-ratios. For the children aged

13–14 years, data for 242 centres in 98 countries with 814 836 participants were submitted to the ISAAC International Data Centre for data analyses. For children aged 6–7 years, data for 165 centres in 65 countries with 421 544 participants were submitted. Adherence to the ISAAC protocol was assessed, and centres with serious deviations from protocol (<70% response rate for the adolescents and <60% for the children, and centres with <1000 participants for both age groups) were excluded from the worldwide data analyses.[19,23] For inclusion in the final analysis, centres needed 70% or more of participants with data for the use of cooking fuels and all covariates. SAS version 9.1 was used for all analyses.

Role of the funding source

The study sponsors had no role in the study design, data collection, analysis, data interpretation, writing of the report, or the decision to submit the paper for publication. The authors had the responsibility to write and submit the paper for publication, with the involvement of the ISAAC Phase Three Study Group. The corresponding author had full access to all the data and the final responsibility to submit for publication.

Results

Data were collected between 1999 and 2004. In the initial statistical models, there were 198 398 children aged 6–7 years from 70 centres in 29 countries (figure 1) and 314 309 children aged 13–14 years from 108 centres in 47 countries (figure 2). Tables 1 and 2 show the distribution of the use of different types of fuel for cooking by region for the two age groups (see appendix for the prevalence rates of the various health outcomes in relation to the use of different types of cooking fuel in the two age groups). In the final multivariate analysis, only those children with complete covariate data were included (figures 1 and 2). As shown in tables 1 and 2, the highest percentages for the use of any open fire or open fire only were from Africa, the Indian subcontinent, and the Asia-Pacific region. For the initial and final multivariate analyses in both age groups, we detected statistically significant and consistent associations between the use of an open fire for cooking and current symptoms of wheeze and asthma (tables 3 and 4). In the multivariate analyses for children aged 13–14 years, the "use of open fire only" for cooking was associated with current wheeze as assessed by both the written and video questionnaires (table 4). In children aged 6–7 years, "use of open fire only" for cooking was associated with current wheeze, severe asthma symptoms, and ever reported asthma (table 3). Furthermore, in children aged 13–14 years, the use of open fire only for cooking was associated with ever reported eczema and current symptoms of eczema, and the use of open fire in combination with other fuels for cooking was also associated with ever reported eczema and current symptoms of eczema (table 4). In those aged 6–7 years, the association between the symptom of wheeze or severe asthma with the use of open fires only seemed stronger compared with use of open fire in combination with other fuel (table 3).

Tables 5 and 6 show the association between current wheeze and the use of different types of cooking fuel stratified by sex and country affluence. We did not detect any significant interaction between sex and the use of different fuels in their associations with current wheeze. When stratified by country affluence, the associations with current wheeze were statistically significant for the two age groups for any open fires and open fire only in non-affluent countries only, but tests for interaction between country affluence and use of different fuels in their associations with current wheeze were not significant (appendix).

In both age groups, symptoms of wheeze and ever reported asthma were not associated with the use of gas as a cooking fuel (table 7). Furthermore, none of the associations of these outcomes with gas cooking was statistically significant when stratified according to sex or country affluence in either age group (tables 5 and 6).

	N	Multiple non-fire fuels (%)	Other fuel only (%)	Any open fire (%)	Open fire only (%)	Gas only (%)	Electricity only (%)
Africa	2308	0%	42%	21%	0%	23%	14%
Asia-Pacific	27 022	11%	1%	1%	2%	78%	7%
Eastern Mediterranean	14 977	3%	<0·5%	1%	<0·5%	94%	1%
Indian subcontinent	42 521	4%	9%	3%	4%	79%	1%
Latin America	46 586	3%	<0·5%	1%	1%	91%	5%
North America	3948	1%	0%	<0·5%	0%	67%	32%
Northern and eastern Europe	15 139	5%	<0·5%	1%	3%	65%	26%
Oceania	10 810	7%	<0·5%	<0·5%	1%	9%	82%
Western Europe	35 087	4%	1%	<0·5%	1%	61%	33%
All centres	198 398	5%	3%	1%	2%	74%	15%

Table 1: **Global use of different types of fuels for cooking (children aged 6–7 years)**

	N	Multiple non-fire fuels (%)	Other fuel only (%)	Any open fire (%)	Fire only (%)	Gas only (%)	Electricity only (%)
Africa	27 563	6%	3%	11%	18%	43%	18%
Asia-Pacific	49 820	8%	4%	3%	3%	71%	12%
Eastern Mediterranean	15 523	4%	1%	2%	<0·5%	91%	3%
Indian subcontinent	41 703	3%	8%	6%	3%	78%	1%
Latin America	79 606	5%	<0·5%	3%	2%	81%	9%
North America	5290	1%	1%	1%	0%	54%	43%
Northern and eastern Europe	26 922	7%	<0·5%	2%	3%	53%	35%
Oceania	19 282	10%	1%	6%	12%	19%	53%
Western Europe	48 600	6%	1%	<0·5%	1%	57%	35%
All centres	314 309	6%	2%	4%	4%	66%	18%

Table 2: **Global use of different types of fuels for cooking (children aged 13–14 years)**

	Adjusted model		Multivariate analysis	
	Any use of open fire	Use of open fire only	Any use of open fire	Use of open fire only
Current wheeze	1·78 (1·51–2·10)	1·79 (1·52–2·10)	1·51 (1·25–1·81)	2·17 (1·64–2·87)
Current symptoms of severe asthma	1·83 (1·42–2·35)	1·80 (1·40–2·32)	1·33 (1·02–1·73)	1·79 (1·18–2·70)
Asthma ever	1·37 (1·10–1·71)	1·26 (1·06–1·49)	1·32 (1·08–1·61)	1·45 (1·03–2·03)
Current symptoms of rhinoconjunctivitis	1·24 (0·97–1·59)	1·06 (0·86–1·30)	1·02 (0·80–1·30)	1·12 (0·74–1·69)
Hay fever ever	1·16 (0·90–1·49)	1·09 (0·91–1·31)	1·06 (0·84–1·33)	1·20 (0·79–1·82)
Current symptoms of eczema	0·93 (0·73–1·21)	1·14 (0·96–1·35)	1·10 (0·91–1·33)	1·08 (0·75–1·55)
Eczema ever	0·80 (0·64–1·00)	0·97 (0·82–1·15)	0·90 (0·74–1·09)	0·64 (0·45–0·93)

Data are odds ratio (95% CI). The reference category for these estimates is electricity only used for cooking.

Table 3: **Association between any use of open fire and open fire only for cooking and current symptoms of asthma, rhinoconjunctivitis, and eczema (children aged 6–7 years)**

	Adjusted model		Multivariate analysis	
	Any use of open fire	Use of open fire only	Any use of open fire	Use of open fire only
Current wheeze	1·20 (1·06–1·37)	1·19 (1·05–1·35)	1·35 (1·15–1·58)	1·35 (1·11–1·64)
Current wheeze (video)	1·42 (1·18–1·71)	1·37 (1·14–1·64)	1·74 (1·41–2·13)	1·87 (1·46–2·40)
Current symptoms of severe asthma	1·31 (1·12–1·52)	1·29 (1·10–1·50)	1·19 (0·98–1·46)	1·20 (0·93–1·55)
Asthma ever	1·24 (1·10–1·40)	1·23 (1·09–1·39)	1·48 (1·28–1·72)	1·70 (1·43–2·03)
Current symptoms of rhinoconjunctivitis	1·09 (0·96–1·24)	1·07 (0·95–1·21)	1·08 (0·91–1·28)	1·02 (0·83–1·26)
Hay fever ever	1·10 (0·96–1·26)	1·09 (0·95–1·25)	1·15 (0·95–1·40)	1·08 (0·85–1·38)
Current symptoms of eczema	1·35 (1·17–1·56)	1·29 (1·13–1·49)	1·37 (1·13–1·66)	1·33 (1·07–1·66)
Eczema ever	1·23 (1·07–1·42)	1·22 (1·06–1·40)	1·35 (1·12–1·62)	1·42 (1·14–1·76)

Data are odds ratio (95% CI). The reference category for these estimates is electricity only used for cooking.

Table 4: **Association between any use of open fire and open fire only for cooking and current symptoms of asthma, rhinoconjunctivitis, and eczema (children aged 13–14 years)**

Discussion

The findings from this large multicentre survey show that the use of open fires for cooking is associated with symptoms of asthma and ever reported asthma in school children of two age groups: 6–7 years and 13–14 years. The associations were consistent between sexes. Furthermore, the associations were similar using three different validated methods to assess the symptoms of current wheeze or ever reported asthma (self-completed written questionnaire and video questionnaires for children aged 13–14 years and parent-completed questionnaires for children aged 6–7 years).[22,23] When stratified according to country affluence, we found that current wheeze was associated with open-fire cooking in non-affluent countries only.

The potentially detrimental effects of indoor air pollution on the development of respiratory diseases have attracted much attention from the research community. Household air pollution from burning of solid fuels has been shown to be a leading risk factor for global disease burden.[28] The association between acute lower respiratory tract infections and exposure to household burning of biomass has been investigated in several studies and the association has been consistent (panel).[29–31] However, restricted data are available for the relation between burning of biomass and asthma. In epidemiological studies, accurate assessment of exposure can be difficult because the intensity of exposure depends on a range of factors such as proximity to the source of pollution, the duration of exposure, and the ventilation system available in the household. The concentrations of pollution from cooking by open fire with indoor burning of biomass are commonly in the order of hundreds and might be up to several thousand μm/m³ of particulates smaller than 10 μm in diameter (PM_{10}).[32,33] Furthermore, households using biomass fuel in low-income and middle-income countries do not usually have effective ventilation systems to reduce the indoor levels of pollutants. In high-income countries, the effects of gas stoves and other combustion appliances on respiratory symptoms and lung function have been studied extensively. The use of domestic gas appliances has been associated with respiratory symptoms and a diminished respiratory function in children.[34–36] However, the evidence was conflicting as to whether the use of gas cooking is associated with asthma.

About half the world population is exposed to household air pollution from the burning of coal or biomass in open fires, the use of these forms of energy sources have received much attention. The use of biomass fuel has been estimated to be more important than smoking of tobacco as a risk factor for COPD globally.[4] In a meta-analysis done by Kurmi and colleagues, strong associations between the use of solid fuel and COPD (OR 2·80 [95% CI 1·18–4·00]) and chronic bronchitis (2·35 [1·92–2·80)] were seen.[37] Exposure to wood smoke was associated with the greatest risk of development of COPD and chronic bronchitis. In high-income countries, most research studies have focused on the possible effects of the use of gas as cooking fuel. Available data are inconsistent, with some studies showing a positive association between gas cooking and asthma and others showing no association. A multicentre study of children from three Chinese cities showed that exposure to gas cooking was one of the risk factors explaining the higher prevalence of childhood asthma in Hong Kong when compared with children from mainland China.[6] However, the PIAMA birth cohort study did not find any association between gas cooking and any of the respiratory outcomes assessed, including asthma.[38] Furthermore, the results from the European Community Respiratory Health Survey of more than 10 000 adults from 11 countries did not show any association between the use of gas for cooking and obstructive respiratory symptoms.[7] Some of these inconsistencies can be explained by errors in exposure

	Countries (n)	Centres (n)	Children (n)	Multiple non-fire fuels	Other fuel only	Any use of open fire	Open fire only	Gas only
Girls	21	44	48 743	1·31 (1·12–1·54)	0·86 (0·43–1·72)	1·56 (1·19–2·05)	1·93 (1·23–3·02)	0·92 (0·82–1·03)
Boys	21	44	48 983	1·09 (0·94–1·27)	1·10 (0·64–1·90)	1·45 (1·13–1·87)	2·35 (1·64–3·37)	0·99 (0·89–1·09)
Affluent countries	6	19	42 047	1·22 (1·07–1·40)	0·84 (0·45–1·57)	1·27 (0·90–1·79)	1·55 (0·78–3·11)	1·01 (0·92–1·10)
Non-affluent countries	15	25	55 679	1·10 (0·90–1·34)	1·12 (0·61–2·04)	1·49 (1·18–1·88)	2·11 (1·53–2·90)	0·88 (0·76–1·01)

Data are odds ratio (95% CI), unless otherwise stated. The reference category for these estimates is electricity only used for cooking.

Table 5: **Association between cooking fuels and current wheeze by sex or country affluence (children aged 6–7 years)**

	Countries (n)	Centres (n)	Children (n)	Multiple non-fire fuels	Other fuel only	Any use of open fire	Open fire only	Gas only
Girls	31	65	78 550	1·25 (1·06–1·48)	0·72 (0·49–1·06)	1·31 (1·05–1·64)	1·36 (1·04–1·78)	0·98 (0·89–1·09)
Boys	31	65	75 737	1·06 (0·89–1·27)	0·98 (0·70–1·38)	1·39 (1·11–1·74)	1·36 (1·03–1·78)	1·00 (0·90–1·12)
Affluent countries	5	17	43 344	1·08 (0·90–1·31)	1·04 (0·70–1·56)	0·98 (0·61–1·56)	0·75 (0·32–1·75)	1·00 (0·90–1·11)
Non-affluent countries	26	48	110 943	1·18 (1·01–1·39)	0·74 (0·53–1·04)	1·38 (1·16–1·65)	1·39 (1·13–1·71)	0·98 (0·88–1·09)

Data are odds ratio (95% CI), unless otherwise stated. The reference category for these estimates is electricity only used for cooking.

Table 6: **Association between cooking fuels and current wheeze by sex and country affluence (children aged 13–14 years)**

assessment or differences in the toxicity of the pollutant mixtures. The type and efficiency of the ventilation systems could also have affected the relation between gas cooking and respiratory symptoms.

In poor countries, the use of open fire associated with use of biomass burning for cooking is far more common than the use of gas or electricity. Indoor air pollution from biomass burning has been associated with a variety of respiratory illnesses such as respiratory tract infection, asthma, and bronchitis.[39] In a study from Kentucky, USA, adults reported to have used coal or wood indoors for cooking for more than 6 months had an increased risk of asthma (OR 2·3 [1·1–5·0]).[13] A study of 1058 children aged 4–6 years from Guatemala showed that exposure to open fires for cooking was associated with symptom of wheeze (OR 3·4 [1·3–8·5]).[18] A study of 755 children from rural villages in India reported that the use of biomass burning was associated with doctor-diagnosed asthma (OR 4·27 [3·00–4·90]).[40] In addition to many studies showing the association of indoor air pollution and respiratory symptoms, findings from several studies have suggested an association between traffic-related air pollution and symptoms of eczema.[26,41] Our results also showed that there was a consistent association between use of open fire for cooking and reported eczema diagnosis and symptoms of eczema in the older age group, but there was a weak protective effect of the use of open fire only on eczema diagnosis in the younger age group (table 3, multivariate analysis). Two studies have shown a positive association between eczema and the levels of indoor air pollutants such as PM_{10}, nitrogen dioxide, and carbon monoxide.[42,43] The normal skin barrier is impaired in patients with eczema. This defect of skin barrier function might enhance the penetration of environmental pollutants or allergens into the skin, resulting in inflammatory responses and persistent symptoms of eczema. Chronic exposure to pollutants could also disrupt the normal skin barrier resulting in increased sensitivity to chemicals or allergens. Further studies are needed to clarify these associations between environmental pollution and eczema, and to expose the possible underlying mechanisms.

	Adjusted model		Multivariate analysis	
	6–7 years	13–14 years	6–7 years	13–14 years
Current wheeze	0·98 (0·92–1·04)	0·99 (0·94–1·04)	0·96 (0·89–1·03)	0·99 (0·92–1·07)
Current symptoms of severe asthma	1·01 (0·92–1·10)	0·97 (0·91–1·03)	0·97 (0·87–1·09)	0·97 (0·89–1·07)
Asthma ever	0·95 (0·89–1·01)	0·98 (0·93–1·02)	0·94 (0·88–1·02)	0·99 (0·93–1·05)
Current symptoms of rhinoconjunctivitis	1·04 (0·97–1·01)	0·96 (0·91–1·01)	1·00 (0·92–1·09)	0·99 (0·92–1·06)
Hay fever ever	1·02 (0·95– 1·09)	0·96 (0·91–1·01)	1·00 (0·92–1·09)	0·99 (0·92–1·07)
Current symptoms of eczema	0·97 (0·91–1·03)	1·00 (0·94–1·06)	0·94 (0·87–1·02)	1·00 (0·92–1·09)
Eczema ever	0·91 (0·86–0·96)	0·99 (0·93–1·04)	0·93 (0·88–0·99)	1·01 (0·93–1·09)

Data are odds ratio (95% CI), unless otherwise stated. The reference category for these estimates is electricity only used for cooking.

Table 7: **Association between use of gas only for cooking and current symptoms of asthma, rhinoconjunctivitis, and eczema, by age group**

The large sample size, the use of standardised methods of assessment, and validated instruments are the strengths of this study. Findings from four validation studies have substantiated the assocation between current wheeze and asthma-related bronchial hyper-responsiveness or confirmation of asthma by physician assessment.[44–47] Our results are consistent with those of other studies in finding that the use of an open fire for cooking was associated with wheeze symptom and reported asthma in both age groups.

Panel: **Research in context**

Systematic review

We searched PubMed for reports published before March 18, 2013, with the following combinations of the search terms "cooking fuel" and "asthma", and "biomass fuels" and "asthma". We identified 40 and 29 reports, respectively. Most of these reports were review articles or studies of the possible effects of gas cooking in rich countries. There were only seven studies investigating the effects of biomass burning and asthma. Among them, only two studies investigated the association in children and both studies were from poor countries. The results of these studies were inconsistent as to whether exposure to biomass burning was associated with asthma or not.

Interpretation

We report a positive association between cooking with open fires and the symptoms and diagnosis of asthma in childhood in both affluent and non-affluent countries. No association was seen with the use of gas. Because cooking with open fires with biomass or coal is very common, especially in non-affluent countries, more detailed studies are urgently needed to establish whether the relation is causal and to assess intervention strategies.

Although not statistically significantly different, the younger age-group seemed to have higher ORs for current wheeze for the exclusive use of open fires as compared with the use of an open fire in combination with other fuels. When stratified according to country affluence, associations tended to be seen only in non-affluent countries. Many factors might affect the health effects of air pollution generated from open fire cooking. These would include the frequency of use of open fire cooking, the type of housing, and the availability and efficiency of kitchen ventilation systems. Most households using open fires for cooking in less affluent countries are usually not equipped with an efficient ventilation system.[10] By comparison with the situation in less affluent countries, kitchen ventilation is likely to be better in homes in affluent countries and this factor could partly explain the discrepancy in the effect of the use of open fire for cooking between affluent and non-affluent countries. A randomised controlled study of 552 women from rural Mexico showed that the use of an improved biomass stove with lower levels of pollution was associated with a reduction of respiratory symptoms and of lung function decline.[48] A major limitation of our study is that we do not have information related to the frequency of open fire cooking and information about kitchen ventilation that would allow us to test these hypotheses. Our environmental questionnaire did not enquire about information related to exposure during pregnancy such that we could not test if exposure factors during pregnancy were associated with various health outcomes in question. The absence of information about the use of asthma drugs is another limitation. Our results would have been strengthened if we could show the association of asthma drug use and exposure to open fire cooking. Furthermore, family history of allergies is a potential confounder but adjustment for parental allergies in our regression models did not change our results.

There are several factors that could affect the validity of our results. In particular, selection bias and recall bias could have led to a spurious positive association between the exposure of open fire cooking and asthma symptoms. We think this is unlikely to explain the present findings because there is coherence between the initial analyses using all available children and the final analyses in selected children adjusted for important covariates, and the results are consistent across the two age groups using three different methods to identify asthma. By contrast with parents of the younger children, children aged 13–14 years are unlikely to be aware of the potential relation between the exposure and asthma symptoms making recall bias less likely. With regards to possible misclassification of exposure, this problem would bias our results towards the null hypothesis. The negative findings from children exposed to open fire cooking in affluent countries might be explained by the lack of statistical power owing to the small sample size. Determination of whether current asthma symptoms were related to the acute exposure or long term exposure could be of interest, but our risk factor questionnaire did not obtain information about the types of cooking fuel used in early life or when the mother was pregnant with the child. The use of multiple non-fire fuels was associated with wheeze in girls in both age groups, and in the younger children in affluent countries (tables 5 and 6). This category of fuel refers to the use of different combinations including gas, electricity, microwave, and even solar energy. Because many of these fuels are thought to be clean sources of energy, the reason for this association is not clear. However, families who can afford the use of multiple types of fuels might have a higher socioeconomic status and if these were more likely to report symptoms or a diagnosis of asthma, a possibility of residual confounding by socioeconomic status could exists that would not be accounted for by the inclusion maternal education in our statistical model.

If the association between open fire cooking and asthma is causal, this factor might be a major modifiable risk factor of asthma in children worldwide. However, more detailed investigations are needed to confirm and quantify this association, understand the underlying mechanisms, and assess intervention strategies. Our results provide further evidence that public policies and measures to reduce indoor air pollution from burning of biomass will translate into significant health benefits especially in developing countries.

Contributors

All authors participated in the development, design, data collection, analysis, and interpretation of this work. GWKW wrote the first draft and all authors contributed to the writing of subsequent drafts of the paper.

Conflicts of interest

We declare that we have no conflicts of interest.

Acknowledgments

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August 11, 2022

Karen Harbert
President and CEO
American Gas Association
400 N. Capitol St., NW
Washington, DC 20001
via email at KHarbert@aga.org

Re: AMA Resolution 439, "Informing Physicians, Health Care Providers, and the Public that Cooking with a Gas Stove Increases Household Air Pollution and the Risk of Childhood Asthma"

Dear Ms. Harbert:

The American Gas Association requested that I review Resolution 439, "Informing Physicians, Health Care Providers, and the Public that Cooking with a Gas Stove Increases Household Air Pollution and the Risk of Childhood Asthma," which was recently adopted by the American Medical Association (AMA) House of Delegates (HOD) at its 2022 Meeting. I am a Principal at Gradient, an environmental and risk sciences consulting firm. My areas of expertise include toxicology and epidemiology, and their application in human health risk assessments. I have extensive experience evaluating health effects associated with air pollutants and conducting systematic review.[1] I am board-certified in toxicology, and a fellow of both the American College of Epidemiology and the Academy of Toxicological Sciences.

Resolution 439 presumes a causal relationship between the use of gas-fired residential cooking appliances and childhood asthma. The document that introduced this resolution[2] cites a very limited number of studies that are not representative of the broader body of scientific literature. As discussed more below, scientific studies addressing gas-fired residential cooking appliances and childhood asthma have significant limitations, including poor study quality, inadequate control of potential confounders, and potential sources of bias. As a result, these studies do not provide a reliable basis for causal inferences. We also note that the AMA resolution downplays the important role of ventilation for mitigating gas combustion-related and cooking-related air emissions.

Epidemiology Evidence

The document that introduced the AMA Resolution points to findings from three epidemiology studies as supporting the linkage between gas cooking and increased risk of childhood asthma and severity, without acknowledging any of the significant study limitations or the studies' inconsistent findings. The first cited study is the Lin *et al.* (2013) meta-analysis, which combined and integrated the data from 41 epidemiology studies published between 1977 and 2013 of indoor NO_2 and gas cooking on asthma and wheeze in children. The Lin *et al.* (2013) study reported weak, statistically significant associations between gas cooking and

[1] Some recent peer-reviewed publications include: Lynch, HN; Goodman, JE; Bachman, AN. 2021. "Lung physiology and controlled exposure study design." *J. Pharmacol. Toxicol. Methods* 112:107106. doi: 10.1016/j.vascn.2021.107106; Boomhower, SR; Long, CM; Li, W; Manidis, TD; Bhatia, A; Goodman, JE. 2021. "A Review and Analysis of Personal and Ambient $PM_{2.5}$ Measurements: Implications for Epidemiology Studies." *Inhal. Toxicol.* 204(Pt B):112019. doi: 10.1016/j.envres.2021.112019; Goodman, JE; Li, W; Cox, LA Jr. 2021. "Commentary: Using Potential Outcomes Causal Methods to Assess Whether Reductions in $PM_{2.5}$ Result in Decreased Mortality." *Global Epidemiol.* 3:100052. doi: 10.1016/j.gloepi.2021.100052; Prueitt, RL; Li, W; Edwards, L; Zhou, J; Goodman, JE. 2021. "Systematic Review of the Association Between Long-term Exposure to Fine Particulate Matter and Mortality." *Int. J. Environ. Health Res.* doi: 10.1080/09603123.2021.1901864.
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asthma and between indoor NO_2 and wheeze; however, there was no statistically significant increased risk of wheeze in relation to gas cooking or risk of asthma in relation to indoor NO_2. This study had a number of important limitations, including heavy reliance on older cross-sectional study data and the use of data from a heterogeneous set of studies in terms of locations, home characteristics, and ventilation, without any assessment of study quality. Interestingly, one of the senior authors of the Lin *et al*. (2013) study, Dr. Bert Brunekreef, was also an author of a much larger epidemiology study of over half a million children that was published in the same year (2013) and "reported no association between gas cooking and lifetime asthma or current asthma in children when compared to children who lived in households that used electric stoves for cooking" (Wong *et al*., 2013). This study not only included a far larger sample size than all of the studies combined in the Lin *et al*. (2013) study, but also adjusted for sex, region of the world, language, gross national income, maternal education, parental smoking, and six other subject-specific covariates. The AMA Resolution does not mention this much larger, contemporaneous study and its conflicting findings.

The other two studies cited by AMA in support of the resolution, Belanger *et al*. (2013) and Kile *et al*. (2014), are both cross-sectional epidemiology studies. Cross-sectional studies, by design, cannot be relied on for making causal inferences because they cannot assess temporality (*i.e*., whether exposure preceded the observed effect). Cross-sectional studies also do not capture disease development or risk and are limited to capturing only disease prevalence. This study type is especially susceptible to several different kinds of bias; for example, the Belanger *et al*. (2013) study is potentially affected by information bias (due to the reporting of asthma outcomes by parents as opposed to medical professionals), model misspecification bias (due to the highly subjective measurement of asthma severity), and selection bias (due to selective study participation). The Kile *et al*. (2014) study also relied upon parental recall for information on both exposure and study outcomes and is thus susceptible to information bias. Moreover, Kile *et al*. (2014) did not rely on any indoor NO_2 measurement data and could not quantitatively evaluate the relationship between gas stove emissions, ventilation practices, and respiratory outcomes.

Emissions

The AMA Resolution makes the claim that the "use of a gas stove increases household air pollution." While it is true that there are combustion emissions from gas-fired cooking appliances, it is also the case that cooking activities themselves (*e.g*., baking, frying, sautéing various types of food) are sources of air emissions and that cooking with electric appliances is thus also a source of household air pollution.

With respect to increases in indoor NO_2, the AMA Resolution claims that such increases "are significantly higher in homes with gas stoves than homes with electric stoves," citing measurements from the Belanger *et al*. (2006) and Mullen *et al*. (2016) studies. NO_2 measurements from these studies indicate that long-term (6- to 14-day) average concentrations are higher in homes with gas stoves than homes with electric stoves, but the levels are not significant from a health-based standpoint, as they fall below the US Environmental Protection Agency (US EPA) National Ambient Air Quality Standards for NO_2 that are protective of respiratory health effects (US EPA, 2016, 2017).

Ventilation

Ventilation plays an important role in mitigating gas combustion-related and cooking-related air emissions. Yet, the AMA Resolution does not consider this and provides no details on the effectiveness of different ventilation practices, such as outdoor-vented kitchen range hood fans. Instead, the document introducing the AMA Resolution focused on findings from a modeling-based simulation study (Logue *et al*., 2014) that assumes no usage of exhaust ventilation hoods, rather than the findings from the same study showing how air quality impacts can be "mitigated substantially" with usage of vented exhaust hoods. Other measurement-based studies, including the Singer *et al*. (2017) study conducted by researchers at Lawrence

Berkeley National Laboratory, as well as the study by Dobbin *et al.* (2018) conducted by researchers at Health Canada, National Research Council Canada, and Lawrence Berkeley National Laboratory, have demonstrated the important role of vented kitchen range exhaust for reducing both kitchen and whole-house air emissions concentrations.

Conclusion

AMA should understand the strengths and limitations of the documents upon which Resolution 439 is based in order to make a more informed decision. Neither the AMA Resolution itself, nor the document introducing it, provide a well-balanced review of research findings, acknowledge the conflicting evidence, or address key issues affecting the interpretation of these studies, including study quality, study limitations, and the inconsistency of study findings. As discussed in this letter, due to significant limitations, the available studies do not provide a reliable scientific basis for AMA to make causal inferences regarding the relationship between the use of gas-fired residential cooking appliances and childhood asthma.

Sincerely,

GRADIENT

Julie E. Goodman, Ph.D., DABT, FACE, ATS
Principal

email: jgoodman@gradientcorp.com

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American Gas Association

Karen A. Harbert
President & CEO

August 26, 2022

James L. Madara, MD
Chief Executive Officer and Executive Vice President
American Medical Association
330 N Wabash Avenue NO 39300
Chicago, IL 60611-5885

Dear Dr. Madara:

As the President and CEO of the American Gas Association (AGA), which represents more than 200 natural gas utilities that deliver essential energy to 187 million Americans and 5.5 million businesses every day, I can confirm that the industry's highest priority is the safety of our customers, communities, and employees. The natural gas industry delivers life-sustaining energy reliably and safely on both the coldest and hottest days of the year, and the increased use of natural gas has been the single-largest contributor to the U.S. lowering its greenhouse gas emissions to more than 30-year lows. According to an analysis released by the U.S. Department of Energy in March, natural gas is 3.4 times more affordable than any other energy source for providing vital fuel for heating and cooking to Americans, including the most vulnerable populations. In fact, the National Bureau of Economic Research found that 11,000 lives are saved during the winter due to the lower price of natural gas for heating.

With that background, AGA is quite concerned about the incomplete and inadequate scientific basis of the American Medical Association House of Delegates Resolution 439, "Informing Physicians, Health Care Providers, and the Public that Cooking with a Gas Stove Increases Household Air Pollution and the Risk of Childhood Asthma." Reference Committee D drafted and recommended for approval this resolution at the Annual Meeting of the House of Delegates in June 2022.

We recommend that the AMA House of Delegates and Reference Committee D should closely re-examine the basis for and approval of Resolution 439.

The resolution presumes an unsubstantiated causal relationship between gas-fired cooking and childhood asthma based on an uncritical review of a limited and biased selection of the scientific literature. The conclusion of the resolution conflicts with observations in childhood asthma literature and is unsupported by actions from the regulatory agencies and organizations responsible for protecting residential consumer health and safety. The Federal Interagency Committee on Indoor Air Quality (CIAQ), which is comprised of two dozen federal agencies led by the U.S. Environmental Protection Agency (EPA), routinely addresses indoor air quality issues of public importance. The CIAQ has not identified natural gas cooking emissions as a concern related to asthma or respiratory illness. AGA commissioned a third-party, Gradient, to review the studies cited in support of the resolution. Gradient "is an environmental and risk sciences consulting firm renowned for our specialties in Toxicology, Epidemiology, Risk Assessment, Product Safety, Contaminant Fate and Transport, Industrial Hygiene, Geographic Information Systems, and Environmental/Forensic Chemistry." Gradient's stated purpose is to "provide cutting edge risk sciences consulting service that advance science, help governments develop

sound risk policies and answer the most difficult health effects questions." Their analysis, attached to this cover letter, identifies significant deficiencies in the supporting studies.

Gradient concluded that "the available studies do not provide a reliable scientific basis for AMA to make causal inferences regarding the relationship between the use of gas-fired residential cooking appliances and childhood asthma." (See Gradient analysis attached.)

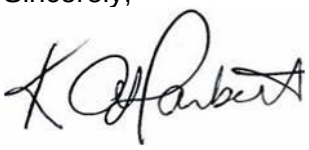
The resolution's recommendation to switch to electric cooking is also unsupported by any substantive evidence that electric cooking is cleaner when cooking byproducts are considered. Indoor air quality studies have consistently found that emissions from the cooking process—not solely from the burner or heat source operation—represent the chief concern for indoor air quality. Switching to electrical appliances is not an effective strategy to address indoor air quality because the emissions of concern are dominated by the smoke and grease from cooking, regardless of the energy source used in conventional residential appliances.

As stated previously, the natural gas utility industry is fully committed to the health and safety of our customers and to reducing emissions. As concerns over emissions from gas ranges are raised and debated, the natural gas industry is focused on bringing objective technical information to the discussion. In collaboration with research organizations, AGA and appliance manufacturers continue to develop information and educate consumers, employees, and regulators about the safety of natural gas cooking appliances and ways to reduce cooking process or combustion emissions such as ventilation. These groups are heavily engaged in promoting the safe use of natural gas appliances through the development of standards for the design of natural gas appliances, participating in building safety codes and standards proceedings, and federal agency reviews.

Doctors, like energy utilities, are vital and trusted members of the communities in which we serve. This resolution, which suggests doctors take actions based on incomplete analysis of existing scientific literature, does not appear to hold up to the level of accountability that science and the AMA Code of Medical Ethics require.

Please share this letter and accompanying Gradient analysis with the members of the Reference Committee D listed below. We look forward to your review of this analysis and response.

Sincerely,



cc: House of Delegates, Reference Committee D

Ankush K. Bansal, MD
Florida Medical Association
Chair, Reference Committee D
American Medical Association

Jade A. Anderson
Resident and Fellows Section, AMA

Nicolas Argy, MD, J.D.
Massachusetts Medical Society

Man-Kit Leumg, MD
California Medical Association

Jean R. Hausheer, MD, FACS
Oklahoma State Medical Association

Laurel Ries, MD (Alternate)
Minnesota Medical Association

Sherif Z. Zaafran (Alternate)
Texas Medical Association

Issues that Render the Sierra Club/UCLA Study of *Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California* Not Useful for Decision-Making Purposes

Daniel Tormey, Ph.D., P.G., Steve Huntley

Catalyst ENVIRONMENTAL SOLUTIONS

CALIFORNIA RESTAURANT ASSOCIATION

Introduction

The report *Effects of Residential Gas Appliances on Indoor and Outdoor Air Quality and Public Health in California* (UCLA Report), published in April 2020, was prepared on behalf of the Sierra Club by the UCLA Fielding School of Public Health. Several cities in California have passed electrification policies for new construction, and such programs are being considered Statewide. Most of the focus on electrification efforts has been on reducing greenhouse gas emissions in general. The UCLA Report takes a different perspective and focuses on potential health effects rather than greenhouse gas emissions. The UCLA Report advocates that replacing natural gas-fired stoves and ovens with electric appliances would have public health benefits and continued use of natural gas-fired appliances will result in adverse health effects. The discussion of these effects is divided into two main sections: (1) indoor air quality and health effects and (2) outdoor air quality and health effects.

As discussed in this Technical Memorandum, there are several significant flaws in the UCLA Report that undermine its use in decision-making on the topic of the health effects of natural gas stoves and ovens. We identify five major issues and three other issues for this conclusion. The major issues are as follows:

Issue 1: Indoor air modeling results presented in Table 2-2 of the UCLA Report are incorrectly compared to NAAQS and CAAQS. Had the UCLA Report made the correct comparisons, it would have concluded that there are no adverse health impacts from indoor use of natural gas appliances.

Issue 2: The UCLA Report cites several references that conclude that indoor air quality is more a function of what is being cooked, rather than the fuel used for cooking. Emissions from cooking oils and foods would remain in indoor air whether or not there is a transition from natural gas to electric cooking appliances.

Issue 3: The UCLA Report does not consider unanticipated consequences of replacing natural gas with electric stoves and ovens. The focus is solely on combustion of natural gas. Considering the UCLA Report advocates for eliminating natural gas for stoves and ovens, the consequences of electrification (cost and disproportionate adverse impacts to disadvantaged communities, availability, hazards) are certainly relevant and belong in the decision-making process.

Issue 4: The results of the UCLA Report depend upon a sequential series of assumptions, some of which are unsupported by the literature. The approach of the paper leads to compounding (increasing) these uncertainties rather than reducing them.

Issue 5: Numerous statements throughout the UCLA Report are not supported by the data provided or the references cited. Because the UCLA Report is built on data in the published literature, this problem indicates a flawed foundation for the findings.

The technical basis for each major issue, as well as the three other issues, are described in the next sections.

Major Issues

Issue 1: Indoor air modeling results presented in Table 2-2 of the UCLA Report are incorrectly compared to NAAQS and CAAQS. Had the UCLA Report made the correct comparisons, it would have concluded that there are no health impacts from indoor use of natural gas appliances.

Table 2-2 in the UCLA Report presents the key results for the indoor air modeling exercise. The results are divided into two categories for indoor air appliance emissions: (1) stoves and ovens and (2) stoves only. In both cases, indoor air modeling was conducted assuming no venting of appliance emissions to the outside. Within each of these two categories, indoor air concentrations of CO, NO_2, and NO_x are presented under four cooking time scenarios: (1) peak (maximum) concentration, (2) 15-minute cooking time, (3) 1-hour cooking time, and (4) 2-hour cooking time. The following discussion focuses on the three purported exceedances of NAAQS and/or CAAQS as presented in Table 2-2.

Note that of the chemicals presented in Table 2-2, NAAQS and CAAQS are only available for CO and NO_2. NAAQS and CAAQS have not been developed for NO_x. For CO, specific NAAQS and CAAQS are only available for 1-hour and 8-hour averaging times. For NO_2, specific NAAQS and CAAQS are only available for 1-hour and annual arithmetic mean averaging times. Table 2-2 of the UCLA Report did not present modeling results for either 8-hour or annual arithmetic mean averaging times. Therefore, the only relevant comparisons that can be made using UCLA modeling results are CO and NO_2 1-hour average concentrations as compared to their respective 1-hour time-averaged NAAQS and CAAQS; these comparisons are presented in the table below.

Table 1. Comparison of UCLA 1-hour Average Modeled Air Concentrations to Relevant CAAQS and NAAQS

Carbon Monoxide	1-hour Average
CAAQS	20,000
NAAQS	35,000
Stoves and ovens¥	2,300¥
Stoves only¥	900¥

Nitrogen Dioxide	1-hour Average
CAAQS	180
NAAQS	100
Stoves and ovens¥	19¥
Stoves only¥	11¥

All concentrations in ppb.

¥ Modeled 1-hour average concentration as reported in Table 2-2 of the UCLA Report.

As shown in the above Table 1, for both CO and NO_2, the modeled indoor air concentrations for Stoves and ovens and for Stoves only are nearly 10-fold below their respective CAAQS and NAAQS, demonstrating a large margin of safety and absence of potential adverse health effects, even under the unrealistic assumption of no venting of stove and oven exhaust.

In contrast to the appropriate comparison presented in Table 1 (above), the UCLA Report presented several comparisons that are not appropriate nor realistic. For comparison to NAAQs and CAAQs, the UCLA Report compared peak (maximum) concentrations directly to 1-hour NAAQs and CAAQs. **The comparison of maximum peak concentrations to a 1-hour standard is not correct and certainly not relevant for assessing health risks.** The 1-hour NAAQS and CAAQS represent health effects thresholds associated with 1-hour time averaged exposures. It is meaningless to compare a maximum to an average. When the incorrect method of the UCLA

Report is applied, the maximum peak NO_2 concentrations for stoves and ovens (860 ppb) and stoves only (400 ppb) exceeded the 1-hour NO_2 NAAQS of 100 ppb and the 1-hour NO_2 CAAQS of 180 ppb. In contrast, when the average concentrations under the 1-hour and 2-hour cooking scenarios are compared to the 1-hour NAAQS and CAAQS, there are no exceedances. Therefore, the argument that natural gas appliances cause adverse health impacts because they exceed air quality limits is not supported by the data presented in the study.

The UCLA Report has a similarly incorrect comparison for assessing potential chronic exposures. The UCLA Report states on page 20, "[w]e compare the modeled 8-hour time-averaged CO concentrations to the 8-hour CO thresholds, and the 24- hour time-averaged NO_2 concentrations to the chronic NO_2 thresholds, under three cooking-time scenarios (15 minutes of cooking, 1 hour of cooking, and 2 hours of cooking." However, the only chronic exposure exceedance shown in Table 2-2 for NO_2 under the stoves and ovens scenario is apparently based on comparison of 1-year annual NAAQs (53 ppb) and CAAQS (30 ppb) to a calculated 24-hour time-averaged concentration (34 ppb). **A 24-hour time-weighted average concentration cannot properly be compared to 1-year annual standards.** While the calculated 24-hour time-weighted average concentration may be a reasonable estimate of exposure concentration over the course of 24 hours, it is not a reasonable estimate of exposure concentration over the course of an entire year. The unrealistic underlying assumption for this comparison is that cooking, using both stove and oven, without venting, would take place in a residence for 2-hours every single day for 365 days per year. This is contrary to available data on residential occupancy and appliance use and is inconsistent with standard risk assessment practices that recommend assessment of reasonable maximum exposures, often referred to as the RME (DTSC 2015[1]).

Based on data provided by the USEPA[2] for the amount of time spent indoors at a residence by age group, the age group that spends the most amount of time indoors is >65 years. Based on these data, this age group representing the upper-bound exposure spends on average 82% of their time indoors at their residence. Therefore, these maximally exposed individuals would experience no exposure 18% of the time or 66 days each year. Adjusting the 24-hour time-weighted NO_2 concentration of 34 ppb by this factor alone reduces the time-averaged NO_2 concentration to 28 ppb, which would eliminate any exceedances since it is below both NAAQs (53 ppb) and CAAQS (30 ppb). Even this comparison is considered to be highly conservative (and unrealistic) as it assumes that none of the stove and oven appliance emissions are vented to the outside and that these individuals >65 years in age cook every day using both stove and oven at full capacity for 2 hours each day.

Issue 2: The UCLA Report cites several references that conclude that indoor air quality is more a function of what is being cooked, rather than of the fuel used for cooking. Emissions from cooking oils and foods would remain in indoor air whether or not there is a transition from natural gas to electric cooking appliances.

The available data indicates that indoor air quality is more a function of what is being cooked than the fuel used for cooking. The UCLA Report's conclusions gloss over this fact. The UCLA Report does not include this fact in the summarized major issues. Yet the Report is forced to acknowledge this issue repeatedly: it notes that "there are indoor air quality issues associated with the use of gas cooking appliances that will remain despite the implementation of electrification, and we do not account for this. Some PM emissions are associated with cooking oils and foods, and there are no mitigation methods for this, other than the use of ventilation devices such as range hoods. We do not claim that the transition to electric appliances would make a substantial difference in terms of emissions from cooking oils and food.[3]" It also notes that "although many studies have measured $PM_{2.5}$ and UFP [ultrafine particle] emissions from cooking with various types of food

[1] DTSC. 2015. PEA Guidance Manual. October.

[2] USEPA. 2011. Exposure Factors Handbook: 2011 Edition. September. EPA/600/R-090/052F

[3] Page 30 of UCLA Report

and cooking oil, these particulate emissions were often attributed to the food and cooking method rather than the operation of gas appliances.[4]" The UCLA Report also acknowledges that "[o]ne caveat mentioned previously is that cooking can be a significant source of exposure to $PM_{2.5}$ due to heating and combustion of food and cooking oil, resulting in indoor concentrations far in excess of the NAAQS 24-hour threshold.[5]"

The UCLA Report[6] further states, "Gas stoves have been associated with increased levels of indoor CO in California homes, but these increases in concentrations are generally negligible,[27,49,51,52]" and "studies measuring PM2.5 emissions found that increases attributed solely to gas kitchen appliances (with no cooking of food involved, though sometimes a pot of water was heated) were negligible.[49,52]"

While it is clear that what is cooked can have a significant effect on indoor air quality, the UCLA Report buries this beneath the headline statement[7] that natural gas stoves and ovens exceed NAAQS and CAAQS. Moreover, while it is clear that the emissions of some pollutants (in particular CO and PM) from home appliance natural gas usage are negligible, the UCLA Report attempts to implicate these very same pollutants in the context of health effects associated with residential natural gas appliance use. As generally concluded by the references cited in the UCLA Report, PM emissions from gas stoves and ovens are elevated during food cooking but are negligible when burners are on without food cooking, and therefore provide no basis for inferring adverse health effects.

Issue 3: The UCLA Report does not consider unanticipated consequences of replacing natural gas with electric stoves and ovens. The focus is solely on combustion of natural gas. Considering the UCLA Report advocates for eliminating natural gas for stoves and ovens, the consequences of electrification (cost and disproportionate adverse impacts to disadvantaged communities, availability, hazards) are certainly relevant and belong in the decision-making process.

The UCLA Report correctly notes that it does not provide any sort of cost benefit comparison between electric and natural gas stoves and ovens. The UCLA Report notes "[w]e also did not assess any exposures or other dangers associated with electrification, as we focus on combustion pollutants in this report…[t]his report does not compare the benefits and costs of electrification versus improving range hood use and efficiency in terms of reducing indoor air pollution. This is an important consideration that needs to be included in any full-scale assessment of indoor air pollution mitigation techniques.[8]" The UCLA Report notes other studies do provide such cost-benefit analysis, but the citation it provides did not do so.[9]

Another unintended consequence of following the advice of the UCLA Report is that it fails to address the disproportionate economic impact on low-income individuals and families resulting from the higher cost of electrification and elimination of natural gas as an economically efficient energy source. A recent study published in January 2021 by the Berkeley and UCLA Schools of Law[10] has proposed a policy resolution for the

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[4] Pages 9 and 12 of UCLA Report

[5] Page 13 of UCLA Report

[6] Pages 12 and 13 of UCLA Report

[7] A statement that is incorrect, as described in Issue 1 of this Technical Memorandum.

[8] Page 30 of UCLA Report

[9] Page 42 of UCLA Report. The citation, reference 15, is to a National Renewable Energy Lab (NREL) report that does not include the words "stove" or "oven" in it, but is a broader view of electrification. No EPRI reference was evident.

[10] Berkeley Law Center for Law, Energy, and the Environment; UCLA School of Law Emmett Institute on Climate Change and the Environment. 2021. Building Toward Decarbonization. Policy Solutions to Accelerate Building Electrification in High-Priority Communities.

higher cost of electric appliances compared to natural gas appliances: raise the cost of natural gas. While this resolution would make the cost comparable, it seeks to shift the cost burden to low-income individuals and families who rely on natural gas as an affordable energy source by artificially increasing natural gas rates to conform with higher electric rates. The effect of this policy would be to reduce demand for natural gas while financially impacting low-income individuals and families.

Even in the absence of focused policy efforts to increase the cost of natural gas to align with electricity costs, as discussed in the Berkeley/UCLA Schools of Law study, the overall shift away from natural gas usage to full electrification will over time result in gradual increased costs to those dependent on natural gas. As discussed in the National Bureau of Economic Research (NBER) working paper recently published by Davis and Hausman (2021)[11], during the period of this shift from natural gas to electrification, historical capital cost recovery, pipeline and other infrastructure maintenance, and operating costs will remain the same, yet natural gas revenues based on declining consumer usage will decrease. Consequently, the shortfall in revenues will need to be resolved by increasing natural gas usage rates to remaining consumers. Since low-income individuals and families have less financial capabilities to shift from natural gas appliances to electric appliances, it is these disadvantaged subpopulations that will be forced to bear the majority of these increased costs of natural gas.

The UCLA Report also notes that eliminating combustion of natural gas in stoves and ovens will typically lead to increased natural gas combustion at power plants: "One aspect to keep in mind throughout this analysis, which will be mentioned again in the Results and Discussion section, is that electricity generation at gas power plants emits both GHGs and criteria air pollutants. Even if all residential gas appliances were transitioned to electric appliances, the electricity required to power these appliances must still be generated by some form of fuel, and gas power plants currently produce almost half of the electricity generation in the state.[12]"

As illustrated in Figure B-5 of the UCLA Report, the contribution of NO_x from residential gas appliances to outdoor air as compared to the total NO_x emissions from all sources in California is very small. Therefore, the relative net beneficial impact of reduced NO_x to outdoor air from the elimination of residential gas appliances is very likely close to zero given the need to supplement electrical generation with other fuel-dependent power sources. This is also likely the case for the other gas combustion by-products evaluated in the UCLA Report such as CO, PM, and NO_2.

Overall, these unintended consequences of following the advice in the UCLA Report undermines the purported benefits highlighted in the report.

Issue 4: The results of the UCLA Report depend upon a sequential series of assumptions, some of which are unsupported by the literature. The approach of the paper leads to compounding (increasing) these uncertainties rather than reducing them.

The UCLA Report acknowledges that the literature and underlying data are uncertain and inconclusive, and that they collected no new data, and yet their approach was to apply an uncertain model in order to address the uncertainty in the literature data. That is, the underlying data on all these issues is inconclusive, lacking, or in some cases contradictory, yet the Report purports to "analyze" it to draw "clear" conclusions. By relying on the same uncertain data, the model simply compounds this uncertainty with model-related uncertainty:

Page 17: "While there is clear evidence of a relationship between indoor air quality and health, and combustion falls under that domain, there is some inconclusive literature related to gas appliance use and

[11] Davis, L.W. and C. Hausman. 2021. Who Will Pay for Legacy Utility Costs? NBER Working Paper 28955.

[12] Page 33 of UCLA Report.

specific health effects. The broader relationship between NO_2 and adverse health effects is well-established but a recurrent theme in the literature is the uncertainty regarding the link between indoor NO_2 exposures from gas combustion and respiratory illness. [30,31,113,117]"

Page 29: "Due to the limited scope of this project, we did not conduct any primary data collection; we only analyzed existing literature and datasets. While we used as many relevant data sources as we could access, data paucity was a major limitation for this report. Particularly for conducting future quantitative analyses with regard to equity, the development of additional, publicly available databases to include more detailed and higher spatial resolution data would be a significant asset."

Page 17-18: "While several studies investigating gas appliances and asthma exacerbation produced mixed results, evidence supports a clearer association between gas appliances and asthma and respiratory symptoms in children with one meta-analysis reporting that children living in homes using gas for cooking have a 42% higher risk of having asthma.[33] While we did not estimate the association between specific health symptoms and use of gas appliances, our literature review and analysis aim to clarify the relationship between pollutants associated with gas appliance use and human health…To our knowledge, there are no existing literature review and secondary analysis studies that tie together indoor air quality modeling for various pollutants, housing types, and low-income vulnerability in California."

In conducting studies of the type presented in the UCLA Report, the uncertainties at each step compound, leading to even more uncertain results. While the UCLA Report purports to improve understanding of the effects of indoor combustion of natural gas for cooking, the study design leads to greater uncertainty and less understanding.

Issue 5: The UCLA Report contains numerous statements that are not supported by the data provided or the references cited. Because the UCLA Report is built on data in the published literature, this problem indicates a flawed foundation for the findings.

The UCLA study is a literature-based study; that is, it relies on studies in the published and at times peer-reviewed literature. However, many of the statements made in the report do not correspond to the cited literature. A few examples are provided, which call into question the foundation of this report.

***Example 1*:** In the first paragraph of Section 1.2 it states, "[h]owever, there are significant risks associated with the burning of gas in residences, due to the indoor emission of pollutants, such as CO and formaldehyde (from incomplete combustion), as well as nitrogen oxides (NO_X) such as NO_2 (caused by the oxidation of nitrogen during combustion). Other hazardous compounds emitted from the burning of gas inside homes include volatile organic compounds (VOCs), sulfur oxides, and PM.[20] "

The statement is misleading. The reference cited (Reference 20) is USEPA (1998) *Compilation of Emission Factors*, specifically Section 1.4 (Natural Gas Combustion). This document includes residential furnace and boiler emission factors for CO, formaldehyde, NO_x, NO_2, VOCs, sulfur oxides, and PM. However, there is no mention of potential health risks or the burning of gas in residences in this USEPA document. The UCLA Report provides no basis or specific reference for the statement that "there are significant risks associated with the burning of gas in residences, due to the indoor emission of pollutants…"

Furthermore, use of the term "significant" in scientific reports generally implies statistical significance. The phrase "statistically significant" is used several times in the UCLA Report, but never in the context of the actual evaluations. Not only does USEPA (1998) not refer to statistically significant health risks for any pollutant, as already noted, but in the two instances where the UCLA Report specifically discusses formaldehyde, it acknowledges that there is no statistically significant association between gas appliance use and indoor air

formaldehyde concentrations. On pg. 13, the UCLA Report states: "Gas appliances also emit formaldehyde,[27,44,62] but some studies did not find a statistically significant association between gas appliance use and indoor formaldehyde concentrations.[45,46,74]" In this instance, the reference is to the absence of statistical significance. And on pg. 14 of the UCLA Report, it states: "However, an LBNL study of California homes found that although 95% of homes tested had formaldehyde concentrations above the OEHHA chronic REL, these levels were not statistically significantly associated with gas appliances.[45]" and "Due to the lack of emission data and statistically significant evidence reported in the primary literature, we did not include formaldehyde or acetaldehyde in our quantitative analysis." In this instance, the reference is also to the absence of statistical significance. Despite acknowledging the *absence* of any statistically significant formaldehyde emissions associated with gas appliances, the UCLA Report nevertheless asserts "there are significant risks associated with the burning of natural gas in residences, due to the indoor emission of . . . formaldehyde."

Moreover, in Section 2.2.1 Emission Factor Database, and specifically the first subsection entitled *Results of Statistical Analyses*, the only reference to statistical analyses or statistical significance in this entire subsection is as follows: "Consistently, as the year of the publication from which EFs were gathered became more recent, the ng/J emissions decreased (e.g., a paper in 1995 would report higher emissions than a paper published in 2009, with a statistically significant difference); this indicates that emissions have reduced over time. For NO_X, there is a statistically significant increase in EFs for appliances designed to be vented outdoors (e.g., water heaters and home heating devices)." No references were provided for either the 1995 paper for the 2009 paper, and no reference is provided for the statistically significant increase in EFs for water heaters and home heating devices. Moreover, despite the misleading name of the subsection, there is no statistical analyses presented.

Example 2: In Section 1.2 (page 9) it states, "[t]he resulting indoor air pollution can have adverse effects on human health, as Americans spend almost 90% of their time indoors,[21]…" The statement is misleading. The reference cited (Reference 21; Klepeis et al. 2001) does not present any evaluation of potential adverse effects on human health resulting from indoor air pollution. Further, while the survey conducted by Klepeis et al. did report that Americans spend almost 90% (specifically 87%) of their time indoors, **the UCLA Report failed to indicate that only 67% of time is spent inside residences.** Since the focus on the UCLA Report is on residential exposure, 67% of time spent inside residences would be the appropriate metric to present.

Other Issues

Issue	Facts Supporting the Issue	Relevance
The UCLA Report advocates eliminating natural gas stoves and ovens for health reasons. The hypothetical risk, however, is already addressed through existing stove and hood design.	The UCLA Report did not model use of residential appliances under the scenarios of manufacturers' safety recommendations, state regulations, or local ordinances. Can natural gas usage be held accountable for improper use of appliances? Page 18: "Unsurprisingly, the EFs of gas appliances have declined over time, likely due to the technological advances of appliances and pollutant capture technology, which reduce emissions. Consistently, as the year of the publication from which EFs were gathered became more recent, the ng/J emissions decreased (e.g., a paper in 1995 would report higher emissions than a paper published in 2009, with a statistically significant difference); this indicates that emissions have reduced over time. "	The air concentrations of CO, NO_2, and NO_x as reported in Table 2-2 of the UCLA Report are incorrect (over-estimated) because the modeling scenario was not based on use according to manufacturer's requirements (nor on real-world conditions). Therefore, the corresponding health implications discussed in the UCLA Report are greatly exaggerated.
The section on outdoor air quality effects of indoor use of natural gas for stoves and ovens only serves to confuse the issues. For the indoor air emissions exposures, the UCLA Report assumed 0% venting to outdoors; for the outdoor air exposures the UCLA Report assumed 100% venting to outdoors. This is double counting and does not give any consideration to the available science on indoor air ventilation rates and similar relevant subjects. **Furthermore, most of the outdoor air section does not address actual stove and oven emissions, which are a small portion of GHG emissions; instead, it evaluates the effects of reducing fossil fuel emissions on GHG-forming compounds in general, not from stoves and ovens and not related to health effects.**	Page 32-33: "A study modeling the impact of future building electrification found that all-electric homes performed better than mixed-fuel buildings, in terms of both GHG emissions reductions and abatement costs associated with the construction of buildings compliant with the Title 24 California Building Standards.[269]" Page 38: "For the year 2018 (as described in Section 3.2.2), the improvement in outdoor air quality from residential building electrification alone would reduce approximately 354 deaths (all-cause mortality), 304 cases of chronic bronchitis, and 596 cases of acute bronchitis in California (see Table B-5 for confidence intervals for mortality). The most affected counties are the higher Population areas, i.e., Los Angeles County and Orange County, due to the nature of the concentration-response function."	The section on outdoor air quality impacts from indoor use of stoves confuses the issues because it in fact addresses overall GHG impacts and health effects of electrification in general, not solely due to cooking.