Emergency department visits of young children and long-term exposure to neighbourhood smoke from household heating – The Growing Up in New Zealand child cohort study

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ARTICLE INFO
Article history:
Received 5 June 2017
Received in revised form 3 August 2017
Accepted 9 August 2017
Available online 29 August 2017

ABSTRACT
In developed countries, exposure to wood or coal smoke occurs predominantly from neighbourhood emissions arising from household heating. The effect of this exposure on child health is not well characterized.

Within a birth cohort study in New Zealand we assessed healthcare events associated with exposure to neighbourhood smoke from household heating. Our outcome measure was non-accidental presentations to hospital emergency departments (ED) before age three years. We matched small area-level census information with the geocoded home locations to measure the density of household heating with wood or coal in the neighbourhood and applied a time-weighted average exposure method to account for residential mobility. We then used hierarchical multiple logistic regression to assess the independence of associations of this exposure with ED presentations adjusted for gender, ethnicity, birth weight, breastfeeding, immunizations, number of co-habiting smokers, wood or coal heating at home, bedroom mold, household- and area-level deprivation and rurality.

The adjusted odds ratio of having a non-accidental ED visit was 1.07 [95%CI: 1.03–1.12] per wood or coal heating household per hectare. We found a linear dose-response relationship (p-value trend = 0.024) between the quartiles of exposure (1st as reference) and the same outcome (odds ratio in 2nd to 4th quartiles: 1.14 [0.95–1.37], 1.28 [1.06–1.54], 1.32 [1.09–1.60]).

Exposure to neighbourhoods with higher density of wood or coal smoke-producing households is associated with an increased odds of ED visits during early childhood. Policies that reduce smoke pollution from domestic heating by as little as one household per hectare using solid fuel burners could improve child health.

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1. Introduction

Overall air pollution in New Zealand, as indicated by its compliance with the WHO Air Quality Guidelines for fine particulate matter [PM2.5] [Suppl 1], is low relative to many developed countries. This is due to low population density, low reliance on heavy industry, islandic remoteness from other polluting continents and, since the 1970s, stricter controls on emissions (Ministry for the Environment & Statistics New Zealand, 2015). However, one major air quality related concern in New Zealand is the wood or coal smoke emissions from domestic heating (Fisher et al., 2007: Ministry for the Environment & Statistics New Zealand, 2014). Eighty-three percent of daily wintertime PM2.5 originates from the...
burning of solid fuel (usage: 92% wood and 8% coal) in residential areas (Wilton et al., 2015). Regional councils in New Zealand have regulated on the installation of more efficient wood burners (with provision of incentives in some regional councils) and the monitoring of \( \text{PM}_{2.5} \) limit (24-hour mean: \( \geq 50 \mu g \text{ m}^{-3} \)), which must not be exceeded more than once per year at each monitoring site (New Zealand Government, 2004). As a result, from 2006 to 2013 domestic biomass heating in New Zealand reduced by 10% (Statistics New Zealand, 2014) and air quality improved. Over this time interval, there was a 14% reduction in the annual number of premature deaths attributable to anthropogenic particulate air pollution mainly contributed from house heating emissions (Ministry for the Environment & Statistics New Zealand, 2014). This decreasing trend in wood or coal smoke pollution in New Zealand contrasts with the increasing trend in some European countries that have recently considered biomass a renewable fuel under climate change mitigation policies and have incentivised and subsidised the replacement of old wood burners with new efficient ones as a form of domestic heating (Chafe et al., 2015).

In urban areas of developed countries where wood burner installations are regulated (Chafe et al., 2015) there is minimal direct exposure to unvented indoor open household fires. Urban population exposure to wood or coal smoke pollution therefore occurs predominantly by infiltration (unintentional introduction to indoor environment) and depends on the amount of neighbouring emissions (Hellen et al., 2008; Bravo-Linares et al., 2016). These are highest at night during winter. Hence wood or coal smoke exposure in urban developed country settings is geographically localised and seasonal, which creates the potential for confounding and measurement bias if these factors are not considered in analyses (Sheppard et al., 2012).

Despite the relatively few studies on the health effects of residential solid fuel combustion in developed countries (Chafe et al., 2015), as compared with the massive literature on health effects of particulate air pollution (W10, 2013), ambient wood or coal smoke pollution has been estimated to be responsible for 40,000–61,000 premature deaths per year in the total European population (Nguyen et al., 2013; Chafe et al., 2015) and 10,000 in North America (Chafe et al., 2015). Exposure to ambient wood or coal smoke is associated with an increased risk of cardiovascular (McGowan et al., 2002; Sahneueza et al., 2009; Yap and Garcia, 2015) and respiratory diseases (McGowan et al., 2002; Schreuder et al., 2015; Oren et al., 2006; Sahneueza et al., 2009; Gan et al., 2013), systematic inflammation and endothelial dysfunction (Allen et al., 2011).

The few contemporary studies in developed countries that have assessed the effects of ambient wood or coal smoke exposure on health during childhood, have found such exposure is associated with an increased risk of bronchiolitis (Karr et al., 2005), otitis media in infants (Machtyry et al., 2011), and of reduced lung function measured during childhood (aged 6–13 years) (Allen et al., 2008). These population-based studies used a relatively advanced method to assess the health effects of wood or coal smoke exposure in an urban developed country setting, where exposure is dominated by infiltration of ambient particulate matters, called spatial land-use regression modelling. This approach utilises correlations between ambient levels of levoglucosan (a marker of biomass burning) and \( \text{PM}_{2.5} \) as well as ambient temperature as indicators of the likelihood of use of biomass heating (Allen et al., 2008; Karr et al., 2009; Machtyry et al., 2011; Allen et al., 2011; Gan et al., 2013). Other methods include the utilisation of mixed-effect models of daily \( \text{PM}_{2.5} \) data during seasons when homes are heated as indicators of wood smoke exposure (Yap and Garcia, 2015); time-series analyses based on emission inventory report of wood smoke domination in \( \text{PM}_{10} \) (McGowan et al., 2002; Sahneueza et al., 2009), and source apportionment of related chemical species (Schreuder et al., 2006).

While these methods are scientifically sound and potentially comparable, they do not directly measure the density of households emitting wood or coal smoke in the neighbourhood ambient environment. In order to provide more readily translatable evidence for assessing policy effectiveness, we propose the use of census data to measure wood or coal smoke pollution. We assessed the efficacy of this method in an investigation of the relationship between exposure to wood or coal smoke pollution and measures of health in the first three years of life.

2. Methods

2.1. Study sample

We analysed longitudinal data from the Growing Up in New Zealand (Kiwi) child cohort study (Morton et al., 2010), which recruited 6822 pregnant women residing in the Auckland region and its neighbouring Waikato region in 2008. The child cohort consists of the 6853 children (–1% of all births in New Zealand during the study recruitment period) of these women born between March 2009 and June 2010 (Morton et al., 2013). The child cohort is broadly generalizable to the contemporary national birth cohort in terms of socioeconomic status and ethnicity (Morton et al., 2015).

2.2. Data collection

2.2.1. Individual-level data

Data used for this study were collected about the cohort children through face-to-face and telephone interviews with their parents, and through data linkage at repeated time points, including antenatal (during the third trimester of the mother's pregnancy), at nine-months (2009–2011) and two years (2011–2012). Based on a unique National Health Index (NHI) number of each child, we linked the Growing Up in New Zealand data to regional and national datasets. These datasets contained (I) the child's background and gestation (perinatal datasets collected from Auckland District Health Board, Counties Manukau District Health Board, Waikato District Health Board, South Auckland Maternity Care Ltd, and Midwifery & Maternity Provider Organisation Ltd), (II) the child's receipt during infancy of vaccines delivered as part of the national immunization schedule (diphtheria/tetanus/acellular pertussis/haemophilus influenzae type B/hepatitis B/polio vaccine and pneumococcal conjugate vaccine at ages 6-week, 3-months and 5-months from the National Immunization Register data) (Ministry of Health, 2016), and (III) episodes of hospital admission and hospital emergency department (ED) visits (from the New Zealand Ministry of Health National Minimum Dataset of Hospital Admissions and National Non-Admitted Patient Collection) in the first three years of life. In New Zealand, all acute paediatric hospital admissions occur following initial assessment in the hospital emergency department. These admissions are to public hospitals and free to New Zealand citizens and permanent residents.

Our primary outcome measure was non-accidental hospital ED presentations. This includes those that resulted in hospital admission (approximately 36%) and those for which discharge home occurred directly from the ED. We limited ED presentations to those that were coded as emergency or paediatric medicine specialty, which accounted for 99% of the hospital ED presentations for the children in the cohort. Of the ED presentations in these two specialties, 34% resulted in hospital admissions of which 44% were discharged with a principal diagnosis code within the respiratory
chapter of the 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD-10).

2.2.2. Area-level data

Data on the density of households emitting wood and/or coal smoke in the neighbourhood ambient environment were obtained by analysing meshblock data from the 2006 Statistics New Zealand census, assuming the household heating methods in the communities around individual children’s home remained approximately the same. Meshblocks are the smallest geographical statistical unit and aggregate population statistics in New Zealand into approximately fifty thousand areas (median 5.8 hectares). Each area includes an average of 91 persons and 33 occupied private dwellings. We were provided with the number of households using different heating methods for each meshblock, in which, on average, 15 (SD = 12.1) dwellings are heated by wood and 2 (3.7) by coal (Statistics New Zealand, 2014).

2.2.3. Data linkage

We linked the meshblock domestic heating data to the cohort child’s individual-level data using a meshblock number that was computed using geocoding software (QAS Batch v7.51) onto the child’s home address based on a match and clean process against an address database (New Zealand DataFusion) (Suppl 2). Based on the geocoded meshblock numbers, we also linked the individual-level data with a new 2015 urban/rural classification dataset (Statistics New Zealand, 2016a) as well as the 2013 New Zealand Index of Depreciation scores (Atkinson et al., 2014). The deprivation index assigns a deprivation score to each meshblock based upon nine variables from the 2013 census, which reflect multiple dimensions of deprivation (Atkinson et al., 2014).

2.2.4. Exposure to wood or coal smoke

We assessed the cohort child’s exposure in the home neighbourhood environment in terms of the number of households using wood and/or coal heating per hectare (based on 2006 meshblock data) of the child’s home at three time points (antenatal, 9-month and 2-year). We determined the geographical location of their home by questionnaire interview and geocoding methods. We estimated time-weighted averages of cumulative exposure across the three time points to account for the effect of residential mobility on long-term exposure (Końti and Teger, 2000). We used mid-points between the fixed time points of antenatal, nine-month and two-year data collection points to define as exposure duration: days 0–136, days 137–502 and days 503–1095 (cut-off at age three years) in the respective periods. These exposure durations were used as duration-dependent weightings in the calculation, assuming the effect of a unit of exposure is proportional to its intensity for all time points (Vacek, 1997).

2.3. Statistical analysis

Among 6853 cohort children, we included 4444 cases in the data analyses after exclusion due to missing data and non-participation in specific data collection waves used for these analyses (Suppl 3). We computed our binary outcome variable by categorising subjects into those who had a first-time non-accidental hospital ED presentations in their first three years of life (n = 1701) versus those who did not (n = 2743).

We applied multilevel logistic regression (SAS 9.4) to assess associations between this binary outcome variable and the area-level smoke exposure (either as a continuous or quartile categorical variable to investigate dose-response relationships). In these analyses we adjusted for variables describing gender; child’s main ethnic group (level-1), birth weight (by tertile), exclusive breastfeeding duration (<6 months vs. ≥6 months), timely receipt of the scheduled infant immunizations; the number of smokers at home, wood or coal heating of own home, presence of mold/mildew in the child’s bedroom, specific household hardship (putting up with feeling cold to save heating costs and forced to buy cheaper food to afford other things needed); area-level deprivation (by tertile of deprivation score) and urban/rural classification; as well as the random effects due to clustering in area units nested within different regional councils.

In sensitivity analyses, we tested the same model by excluding explanatory variables and by using the outcome variable to represent accidental ED visits as well as non-accidental ED visits in cooler (May to October) and warmer seasons (November to April), which were defined based on the temperature data in the National Climate Database (www.niwa.co.nz). We also conducted additional sensitivity analyses on the use of 2013 meshblock heating data, separating the wood and coal heating data, further adjustment for first emergency department visit before 6-month old, and stratifying children by whether or not they had moved to a different house since their births (Suppl 4).

To test whether ED visits coded as either emergency or paediatric medicine specialty is indicative of respiratory diseases, we used logistic regression to assess the crude associations between non-accidental ED visit events in these two medical specialties with the same-day events of hospital admissions due to respiratory diseases (ICD 10: J00-J06, 20–42, 44–47).

2.4. Ethical approval

Growing Up in New Zealand received ethical approval from the Ministry of Health Northern Y Regional Ethics Committee (NTY/08/ 06/055). Written informed consent for research and data linkage was obtained from enrolled mothers.

3. Results

3.1. Exposure to wood or coal smoke

The distribution of time-weighted average exposure among the cohort children was right-skewed (Fig. 1) with quartile ranges of 0–1.2, 1.2–2.4, 2.4–3.6, 3.6–6.1 and a mean of 2.52 wood or coal heated households per hectare, based on data (n = 4444) included in our final model. The mean number of wood or coal heated households per hectare for these 4444 households did not differ from that for the households of all children with non-missing data for this variable (mean = 2.50, n = 5296), (p-value for z-score = 0.999).

3.2. Hospital admissions

We found that between 2009 and 2013, 38% of the cohort children (n = 4444) experienced a non-accidental visit to an emergency department in the emergency or paediatric medicine specialties in their first three years of life (Suppl 5). Emergency department visits in these two specialties were strongly associated with the same-day events of hospital admissions due to respiratory diseases with an odds ratio of 16.2 [95%CI: 14.2–18.3%].

3.3. Impact of wood or coal smoke exposure on child health

Living in a household within a meshblock with either the third or the fourth quartile of wood or coal smoke exposure was associated respectively with a 28% [6–54%] and 32% [9–50%] excess risk of non-accidental emergency department visits before the age of three years (Table 1). The overall excess risk of a non-accidental
emergency department visit associated with the exposure (as a continuous variable) was 73% [3.3, 11.6] per wood or coal heating household per hectare. Sensitivity analyses showed that the associations between the exposure and emergency department visits remained statistically significant and of similar magnitude in the cooler season but not in warmer season (Table 2).

We examined all mutually-adjusted variables in the full model (Table 1) and found several indicative risk factors of non-accidental emergency department visits, including the child's ethnicity (Maori or Pacific children showed a higher risk compared to New Zealand European or Asian children), having two or more smokers at home, specific household hardship and living in an independent urban area. Protective factors included being female, exclusive breastfeeding for more than six months and living in a medium deprived area.

In the full model we found a linear dose-response relationship between wood or coal smoke exposure and the outcome (p-value for trend = 0.024) and in all sensitivity analyses that showed statistically significant odds ratios (p-value for trend = 0.038–0.045). We did not find this relationship in the crude model (p-value for trend = 0.059) (Table 2).

4. Discussion

We aimed to assess the impact of exposure to wood or coal smoke on child health by investigating associations between non-accidental emergency department presentations and the density of household heating with wood or coal in the home neighbourhood environment of children in their first three years of life. Within a large child cohort study, which is generalizable to the ethnically diverse New Zealand population, we showed that long-term exposure to living areas with higher density of wood or coal smoke-producing households is associated with an increased risk of having non-accidental emergency department visits in the first three years of life. Our findings are in line with the postulated underlying biological mechanisms (Suppl 8) as well as previous studies that have examined the effects of wood or coal smoke exposure on child health (Karr et al., 2000; Macintyre et al., 2011; Allen et al., 2008).

4.1. Strengths and limitations

Some limitations need to be taken into account when interpreting our findings. First, the wood or coal smoke exposure data we report here are based on census data at small area levels but are not precise direct measures of exposure to wood or coal smoke emission that was dispersed to the ambient air by the neighbouring households. They are therefore only indicative with many assumptions, including both between- and within-area similarities such as the correlations between exposure and the density of wood or coal smoke-producing households, emission rates in all households, meteorological and topological factors that could affect dispersion, chemical compositions and toxicity of all emissions, patterns of home location between the wood or coal heating households, and the influence from other neighbouring areas. In addition, the actual personal exposures are often highly variable between individuals and are dependent on exposure-related time-activity patterns, and the housing envelope, infiltration and ventilation methods. For these reasons, our measures should be interpreted as a crude proxy of exposure.

Second, non-accidental emergency department visits for emergency or paediatric medicine is not a common definition in the literature nor a health outcome specific to air pollution exposure. Although we demonstrated a strong association of these emergency department visits with same-day hospital admissions due to diagnosed respiratory diseases, which are usually used as a health endpoint for children's exposure (Zar and Ferkol, 2014), there is no national collection of diagnoses for patients presented to hospital emergency departments but not being admitted. Other limitations that need to be considered when using emergency department visit data include completeness and quality that can be dependent on operational pressures, and the accuracy and consistency in classification of medical specialties that might be related to the diagnostic and screening technologies available at a particular facility (Hirschon et al., 2008).

Third, the potential for residual confounding exists. We might not have adjusted for all potential confounding sources (e.g. efficiencies or designs of the wood burners, building age, household structure and tenure types); however, we adjusted for a comprehensive range of covariates that describe child, family and home environmental and area-level components that predominantly showed expected effect estimates and direction. For example, in studies from the cohort of hospital admissions for all infectious diseases and specifically for acute respiratory infections (Holob et al., 2016; Tin Tin et al., 2016), being female and exclusively breastfed for 6 months or more are associated with a decreased odds of hospital admission while being of Maori or Pacific ethnicity, having smokers in the home and household hardship are associated with an increased odds of respiratory infection hospital admissions within the cohort. We speculate that the national data showing the smaller percentage of two-parent families living in independent urban areas (Statistics New Zealand, 2016b) is the reason behind the elevated risk as shown in the rurality covariate. We are not certain why there was a protective effect in medium versus low deprivation areas. It is possible that this effect relates to heater types most common in the areas of different socio-economic status — with least deprived areas more likely to have multiple heater types including more 'decorative' wood burners as a lifestyle option. This observation is supported by our own data which shows that those living in the least area-level deprivation are associated with both the lowest and the highest density of wood or coal
Table 1
Multi-level logistic regression of non-accidental emergency department visits coded as emergency or pediatric medicine visits in the first three years of life in relation to exposure to neighborhood ambient wood or coal smoke (full model).

<table>
<thead>
<tr>
<th></th>
<th>n (%)</th>
<th>Adjusted odds ratios (95CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood or coal smoke 2nd Q</td>
<td>1111 (25)</td>
<td>1.14 (0.95, 1.37)</td>
</tr>
<tr>
<td>Wood or coal smoke 3rd Q</td>
<td>1111 (25)</td>
<td>1.28 (1.06, 1.54)</td>
</tr>
<tr>
<td>Wood or coal smoke 4th Q</td>
<td>1111 (25)</td>
<td>1.32 (1.09, 1.60)</td>
</tr>
<tr>
<td>Female (Ref: male)</td>
<td>2148 (48)</td>
<td>0.74 (0.65, 0.84)</td>
</tr>
<tr>
<td>Māori (Ref: European/New Zealander)</td>
<td>1058 (24)</td>
<td>1.37 (1.16, 1.62)</td>
</tr>
<tr>
<td>Pacific</td>
<td>482 (11)</td>
<td>1.56 (1.25, 1.94)</td>
</tr>
<tr>
<td>Asian</td>
<td>652 (14)</td>
<td>1.14 (0.94, 1.39)</td>
</tr>
<tr>
<td>Other ethnicities</td>
<td>102 (2)</td>
<td>1.24 (0.82, 1.88)</td>
</tr>
<tr>
<td>Low birth weight (Ref: medium)</td>
<td>1475 (33)</td>
<td>1.12 (0.96, 1.30)</td>
</tr>
<tr>
<td>High birth weight</td>
<td>1480 (33)</td>
<td>0.90 (0.77, 1.05)</td>
</tr>
<tr>
<td>Excl. breastfed ≥6 M (Ref: &lt;6 M)</td>
<td>976 (22)</td>
<td>0.84 (0.73, 0.98)</td>
</tr>
<tr>
<td>Completed vaccination (Ref: no)</td>
<td>4146 (93)</td>
<td>1.13 (0.88, 1.45)</td>
</tr>
</tbody>
</table>
Table 2
Sensitivity analyses on the adjusted odds ratios of 2nd, 3rd and 4th quartile of exposure to neighbourhood ambient wood or coal smoke in the full model for the association with emergency department visits in the first three years of life.

<table>
<thead>
<tr>
<th>Model</th>
<th>n₀/n₁</th>
<th>Odds ratios (95CI)</th>
<th>p-value for trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude model</td>
<td>2743/1701</td>
<td>1.21 (1.01, 1.44)</td>
<td>0.059</td>
</tr>
<tr>
<td>Emergency department visits adjusted for child component only</td>
<td>2743/1701</td>
<td>1.17 (0.98, 1.40)</td>
<td>0.027</td>
</tr>
<tr>
<td>Emergency department visits adjusted for child and health component only</td>
<td>2743/1701</td>
<td>1.17 (0.98, 1.41)</td>
<td>0.024</td>
</tr>
<tr>
<td>Emergency department visits adjusted for child, health and home environment component only</td>
<td>2743/1701</td>
<td>1.16 (0.97, 1.39)</td>
<td>0.018</td>
</tr>
</tbody>
</table>
heating when compared with those living in medium or high area-level deprivation (Chi-Square test p-value<0.0001). Nevertheless, the directions of all other mentioned covariate effects lend support to the validity of the adjusted association between the exposure and area-level deprivation visits we report here.

Our data acquisition through record linkage provides a low cost opportunity to consider census-based environmental indicators and health records in an ongoing cohort study, which has collected detailed information on each child's background demographic characteristics, health and wellbeing, psychological and cognitive development, family, neighbourhood and societal influences. This creates a unique opportunity for ongoing assessments of the health effects of long-term exposure to wood or coal smoke on children from a transdisciplinary perspective within environmental and social science contexts. Compared to previous studies that have examined the effects of exposure on child health (McGowan et al., 2002; Oroz-co-Levi et al., 2006; Schreider et al., 2006; Allen et al., 2008; Kaur et al., 2009; Sahlueda et al., 2009; Machinleyte et al., 2011; Allen et al., 2011; Gan et al., 2013; Yap and Garcia, 2015), our results are unique in that we are able to additionally explore the impact of several socio-demographic and environmental exposures from our cohort data at an individual level. These include ethnicity, exposure to second hand cigarettes at home, wood or coal heating in the child's home, the presence of mold/mildew in the child's bedroom, and the impact of specific measures of socioeconomic hardship (in terms of inability to maintain adequate heating and food consumption choices).

We also differ from the published literature to date in that we did not associate the health outcome with the level of PM$_{2.5}$ concentrations but with a variable that directly indicates wood or coal smoke exposure. This simplistic approach does limit the comparability of our results with the existing literature, but avoids the need to compare the emission compositions within the particle mass concentrations, which could also be due to other emission sources and are often varied in different studies. This approach may be more applicable to preschool children because this age group spends the majority of their time in the home (Rakic et al., 2007), their long-term exposure in the neighbourhood environment as indicated by the census meshblock data that were geographically matched with the home locations is a particularly relevant proxy.

The density exposure variable in terms of the number of wood or coal heating households per area is more readily interpretable (than source apportionment of PM$_{2.5}$) without the need for technical translation and could be easily and periodically obtained in countries with well-developed census data collection. Measuring the number of wood or coal heating households per area in relation to emission control policies could also support decision making, especially when the emission rates and inventory data of different types of woodstove in New Zealand become available (Wilton et al., 2015). For example, considering that a new wood burner could emit more PM$_{2.5}$ each year than 1000 petrol engine cars, setting an emission policy to reduce the number of woodstoves has the potential for greater benefit than would occur from reducing the number of vehicles (Robinson, 2015). Extrapolating from the total number of 121,963 non-accidental emergency department visits for paediatric and emergency medicine in 2013 (Dwyer, 2016) and the 7.3% excess risk in emergency department presentation per wood or coal heating household per hectare in our results, a policy that resulted in one less wood or coal heating household per hectare could yield an annual reduction of 8903 children making emergency department visit(s) in their first three years of life.

4.2. Implication of findings

While we urge all health and environmental policy makers to consider the potential life-long health impacts of young children being exposed to wood or coal smoke, we are also cognisant of the impact of fuel poverty on child health in New Zealand and the potential unintended consequences of restricting heater type and availability (Howden-Chapman et al., 2012). In some areas, burning wood logs collected from the neighbourhood environment is a cheaper option compared to oil, gas or electricity for heating. Children who do not have sufficient heating at home are also at increased risk of poorer respiratory health (Howden-Chapman et al., 2008) and our own data has demonstrated the impact of gas heating on childhood respiratory function (Tin Tin et al., 2016). Thus, the children of families living in poverty may be at increased risk of poorer respiratory health if burning wood is the only alternative to an unheated household. Further, children living in the least secure private rental tenancies are likely to be even more vulnerable to policies that rely on voluntary provision of improved heater quality. On the other hand, attention to the health effects of wood or coal smoke provides additional evidence to better align with the climate change mitigation strategies that also target biomass fuel.

Apart from wood burning, we also identified other independent factors that are associated with an increased odds of emergency department visits, including Maori and Pacific ethnicities, exposure to smokers at home and household deprivation. These findings provide evidence which supports current public health policies related to smoking cessation and social policies related to poverty and vulnerable groups in society.

Wood burning has become an increasing source of fine PM emissions globally (Sigsgaard et al., 2015) and has reached an amount equivalent to the emission from road transport in developed countries, for instance in the UK (Robinson, 2015). In New Zealand, the policy requiring mandatory use of new types of wood burners after 2005 for land areas less than 2 hectares has been under review since 2016. This review is due to be completed in 2017 (Ministry for the Environment, 2016). Our findings can help inform subsequent refinement of this policy.

5. Conclusions

Long-term exposure to wood or coal smoke is associated with non-accidental emergency department visits in the first three years of life. We demonstrated a method based on census information at small geographically unit to indicate the variation of preschool children's exposure to ambient emissions from solid fuel burning and provided quantification of the potential for reductions in health care utilisation if exposure is decreased by reducing the number of wood or coal smoke-producing households per land area.

Declaration of competing financial interests

The authors declare that they have no conflicts of interest and no competing financial interests to share.

Acknowledgements

We acknowledge first and foremost the children and the families who are part of the Growing Up in New Zealand study. We acknowledge the numerous government agencies that fund and support Growing Up in New Zealand, in particular the Social Policy Evaluation and Research Unit (formerly the Families Commission) for their ongoing management of the contract on behalf of the Crown, as well as the ongoing support from Auckland UniServices and the University of Auckland. We thank all the members of the Growing Up in New Zealand research team for their invaluable work in interviewing participants and managing the data used in this.
analysis, as well as the members of Growing Up in New Zealand’s Kaitaki Group and Executive Scientific Advisory Board. We also thank the Ministry of Health for technical information support and provision of the national hospital data.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cnpo.2017.08.015.

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