Health and Economic Impacts of Residential Wood Burning in Metro Vancouver

Prepared for:
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This report has been reviewed by representatives of Metro Vancouver, who commissioned the study, but the interpretation of the results of this study, as expressed in the report, is entirely the responsibility of the consultant authors and does not imply endorsement of specific points of view by Metro Vancouver. The findings and conclusions expressed in the report are the opinion of the authors of the study and may not necessarily be supported by Metro Vancouver. Any use by a third party of the information presented in this report, or any reliance on or decisions made based on such information, is solely the responsibility of such third party.

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File: 527-028.01

Metro Vancouver
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Attn: Julie Saxton, Air Quality Planner

Dear Ms. Saxton,

Re: Health and Economic Impacts of Residential Wood Burning in Metro Vancouver

Hemmera Envirochem Inc. is pleased to provide you with the above noted final report.

We have appreciated the opportunity to work with you on this project and trust that this report meets your requirements. Please feel free to contact the undersigned by phone or email regarding any questions or further information that you may require.

Regards,
Hemmera Envirochem Inc.

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EXECUTIVE SUMMARY

This report provides an assessment and comparison of potential policy options for wood burning devices being considered by Metro Vancouver to reduce residential wood smoke emissions with respect to a variety of outcomes relevant to human health, psychosocial well-being and cost. The study findings are intended to inform decisions about potential policy options to reduce the impacts associated with residential wood smoke emissions.

A comprehensive literature search found several studies describing the health and socio-economic effects associated with residential wood smoke emissions and how these effects have been quantified. A jurisdictional review of policies and programs to address wood smoke emissions and which are relevant to Metro Vancouver was also conducted as were interviews with local public health experts and the academic community so as to help inform local air quality, health and socio-economic issues in Metro Vancouver.

Two potential policy options were considered:

- Option 1) This policy would require indoor wood burning appliances that do not meet emissions standards not be used or replaced with advanced low emission appliances that meet defined emission standards and/or approved certification.
- Option 2) This policy is the same as Option 1 in terms of the requirements to replace or refrain from using conventional wood heating devices; however, there is flexibility with this option to allow for the exemption of low-income households where conventional wood heating devices are the primary source of heat.

Four scenarios representing potential outcomes of the two potential policy options and two different participation rates that reflect when exemptions are not allowed (Option 1) and when they are (Option 2) were considered. The four scenarios represented reductions in ambient fine particulate matter ($PM_{2.5}$) concentrations ranging from 5 percent to 16 percent. The human health and economic benefits associated with reduced $PM_{2.5}$ concentrations were estimated using the Air Quality Benefits Assessment Tool (AQBAT) developed by Health Canada.

The results of the AQBAT modelling assessment indicate that the annual cost benefits associated with the predicted decreases in $PM_{2.5}$ concentrations in Metro Vancouver range from ~$282 million (Option 2, moderate wood smoke contribution to $PM_{2.5}$) to ~$869 million (Option 1, high wood smoke contribution to $PM_{2.5}$) when all health endpoints are considered. Chronic exposure mortality accounts for 92% of total amount. The high cost of mortality is related to the economic valuation model (willingness-to-pay) used to estimate mortality costs, which in AQBAT is ~$6.5 million for each premature death avoided.

Excluding chronic exposure mortality, the annual benefits range from ~$21 million (Option 2, moderate wood smoke contribution to $PM_{2.5}$) to ~$66 million (Option 1, high wood smoke contribution to $PM_{2.5}$) for the Metro Vancouver area. Understanding the benefits associated with avoidance of acute health effects is important when considering the cost-benefit to lower income families, especially those reliant on residential wood burning for heat. Such an examination allows for a comparison of the health benefit gained due to reduced exposure to wood smoke with the potential for poorer health due to less money available to purchase food and other necessities because of the additional costs of switching to certified appliances or an alternate source of heating. Acute health benefits are also more reflective of “out of pocket” costs.

Examination of the differences in cost savings between the two policies show that the acute health-related cost savings are approximately $10 million greater if no exemptions are allowed. However, Option 1 requires costs to be incurred for alternative heating, which may disproportionately affect low income households. Input from health authorities and local experts indicated that equity effects should be considered.

Based on the study results and lessons learned from other jurisdictions as well as input from local experts, significant benefits can be realized from regulatory measures to reduce residential wood smoke emissions. However, there can be adverse effects on the wellness of low income families and others heavily reliant on wood for heating.

Successful implementation of any residential wood smoke reduction programs requires public education outreach programs presenting the association between residential wood smoke emissions, ambient air quality and health.

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ACRONYMS & ABBREVIATIONS

AQBAT	Air Quality Benefits Assessment Tool
BC MOE	British Columbia Ministry of the Environment
CCME	Canadian Council of Ministers of the Environment
CD	Census division
CO	Carbon monoxide
CRF	Concentration response function
CV	Cerebrovascular
Deciview	A measure of the change in light extinction, used for visibility assessment
ER	Emergency room
EV	Endpoint valuation
HA	Hospital admission
IHD	Ischemic heart disease
NOx	Nitrogen oxides
NSPS	New Source Performance Standard
$PM_{2.5}$	Particulate matter with a diameter less than 2.5 μm (10^{-6} m)
PM_{10}	Particulate matter with a diameter less than 10 μm (10^{-6} m)
PSCAA	Puget Sound Clean Air Agency
SOx	Sulphur oxides
US EPA	United States Environmental Protection Agency
VOCs	Volatile organic compounds
PAHs	Polycyclic aromatic hydrocarbons

1.0 INTRODUCTION

Reducing public exposure to residential wood smoke is a common concern among air quality management and health agencies across North America, Europe, Australia and New Zealand. Since at least 2000, the BC Ministry of Environment has made efforts to understand the magnitude of the issue in this province, to promote policies to improve air quality associated with residential wood burning. The BC Lung Association's State of the Air Report 2015 notes that the relationship between levels of wood smoke and the frequency of heart attacks is being investigated in Courtney, Kamloops and Prince George by Health Canada, in collaboration with the BC Ministry of Environment, the Island Health Authority, McGill University and the University of British Columbia. The following report is part of a continuing effort to improve air quality in Metro Vancouver through the evaluation and development of future policy options for residential wood smoke.

To inform the study, a comprehensive literature search was conducted to identify studies describing the health and socio-economic effects associated with residential wood smoke emissions and how these effects have been quantified. This also included a jurisdictional review of policies and related public information programs that have been used to reduce wood smoke emissions and which are relevant to Metro Vancouver. A summary of the documents reviewed as part of the literature search is provided in **Appendix A**. Interviews with local public health experts and the academic community were also conducted to better understand local air quality, health and socio-economic issues. A summary of the interview feedback is provided in **Appendix B**. Finally, technical support on the Air Quality Benefits Assessment Tool (AQBAT) used to estimate health and economic benefits associated with potential policy options was provided by Health Canada.

1.1 PURPOSE OF THIS REPORT

Metro Vancouver is responsible for air quality in the region, and as such is committed to protecting the environment and managing the release of air contaminants. This report provides an assessment and comparison of potential policy options for wood burning devices being considered by Metro Vancouver to reduce residential wood smoke emissions with respect to a variety of outcomes relevant to human health, psychosocial well-being and cost. This report is intended to inform decisions about potential policy options to reduce the impacts associated with residential wood smoke emissions.

1.2 WHAT IS MEANT BY "RESIDENTIAL WOOD BURNING"

Residential wood burning applies to all residential indoor wood burning appliances. This encompasses a wide range of devices including:

- Uncertified and certified wood stoves
- Uncertified and certified fireplace inserts

- Natural fireplaces
- Wood and pellet burning furnaces
- Pellet stoves

This report does not apply to emissions from commercial wood burning appliances such as pizza ovens used for cooking or other commercial wood burning emissions. Also, emissions from outdoor burning of debris or use of wood for camp fires and outdoor cooking have not been considered.

1.3 TYPES OF EFFECTS CONSIDERED

There are both benefits and drawbacks to residential wood burning. On the positive side, residential wood burning can be a relatively cheap source of heating and a source of back-up heating in the event of power or natural gas outages. Many people associate wood burning with comfort and aesthetic enjoyment. On the negative side, residential wood burning has been linked to a wide range of adverse health effects, especially in individuals with pre-existing respiratory and cardiovascular diseases. These effects can lead to increased economic costs such as those related to medical treatment and reduced productivity. There can also be nuisance-related issues such as odour and reduced visibility. These effects are linked to one another in complex ways. Literature relied upon and which describe the health and socio-economic effects associated with residential wood burning is summarized in **Appendix A**. **Figure 1** summarizes these effects and some of their relationships.

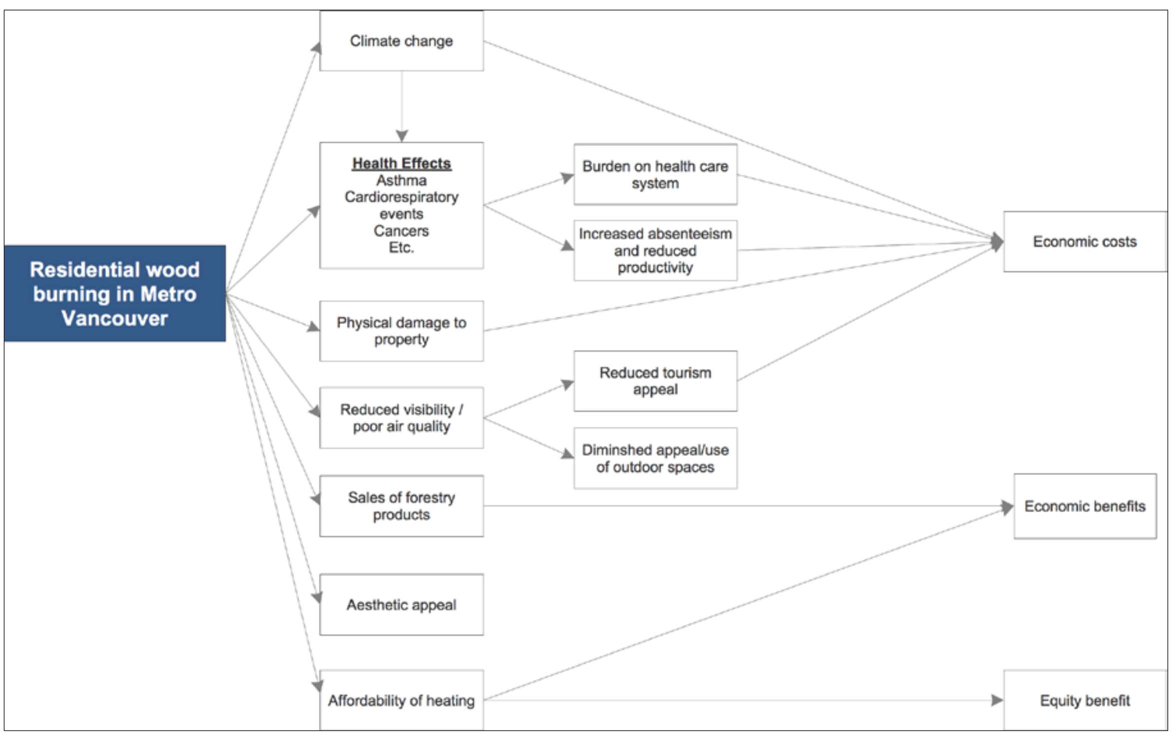

Figure 1 Effects of Residential Wood Burning

While all of these effects may be valid in any given situation, some are more easily characterized than others. This report focuses on those effects for which there is sufficient information to draw evidence-based conclusions about how potential policy options for wood burning devices that may be considered by Metro Vancouver may affect the region's population. These effects are:

- **Adverse health outcomes** that result from exposure to contaminants in residential wood smoke, with discussion on differential effects on vulnerable groups. In particular, increased incidence of mortality and various morbidity health endpoints associated with exposure to $PM_{2.5}$;
- The **burden on the health care system** resulting from these health outcomes;
- **Increased absenteeism and reduced productivity** from these health outcomes;
- The **economic cost** of these health outcomes; and
- **Affordability of heating** and the **economic and equity effects** experienced by economically vulnerable populations.

In addition to these topics, there are a number of other issues that have been raised by local individuals or organizations, or in the published literature, that may also be linked to residential wood burning. These issues, which are not as easily characterized in terms of how they would change under different policy scenarios, are described below. These remain important considerations for any residential wood burning policy, even if they cannot be easily quantified.

Aesthetics

For many people, there is a strong aesthetic appeal to residential wood fires. Residential fires may be perceived as cozy, improving the ambience of a room, bringing emotional significance or eliciting feelings of nostalgia (Databuild Research and Solutions, 2016, Barto 2009). These psychosocial connections may contribute to some people's choice to continue using wood to heat their home, even when potential harmful respiratory effects are known (Reeve, 2013). In addition, there is evidence that some people choose wood burning over other heating options because wood is perceived as a natural and environmentally-friendly alternative to other fuel sources such as oil or gas, despite it being a less efficient source with potential health consequences.

Tourism Appeal and Visibility

Clean air and beautiful views are part of what attracts many tourists to the Metro Vancouver region and to BC in general. High levels of $PM_{2.5}$ and other particulate matter released by wood burning devices can affect visibility. Reduced visibility can affect whether a tourist stays in the area, the length of their stay, and whether they return (BC Visibility Coordinating Committee, 2015). This has been linked to the potential for tourism-related economic losses in the Greater Vancouver area. A study conducted in 2000 estimated that poor visual air quality in the area could lead to a revenue loss of between $4.03 and $7.45 million dollars per event, depending on the severity of visual impairment (McNeill and Roberge, 2000).

High levels of wood smoke could have the potential to impact tourism. Modelling developed by So *et al.* for the Lower Fraser Valley concluded that in order to achieve an improvement of 1.0 'deciview' (a 10% change in light extinction, approximating the perceptible change in visibility), baseline levels of $PM_{2.5}$ would have to be reduced by 17%. As reported in the article, "Model simulations also indicated that "across-the- board" emission reduction policies would result in greater improvements for the "worst 20%" visibility conditions than for the "best 20%" conditions, suggesting that reducing the number of "poor" visual air quality days would be easier than improving the number of "excellent" visual air quality days" (So et al., 2015).

Property Damage and Odour

One study of wood smoke in Europe (Kistler et al. 2012) reported that wood smoke odour becomes recognizable at PM_{10} concentrations as low as 30 µg/m^3 (instantaneous detection), well below Metro Vancouver's Ambient Air Quality Objective of 50 µg/m^3 (24-hour average). The study also reported that while wood smoke odour was not detectable from pellet stoves, there was a large range in odour concentration for different types of wood, ranging from an average odour concentration of 2430 odour units per cubic metre (OU/m^3) for log wood and briquettes and up to 19,000 OU/m^3 for dry leaves[1]. Typically, ambient odours in a community can be considered to be offensive at concentrations of 5-10 OU/m^3. Therefore, wood burning has the potential to cause community odour problems even when the ambient air quality objective is being achieved, although the degree of offensiveness of the resultant odours may depend on the type of fuel being burned, the number of wood burning devices in use and the meteorological conditions under which the burning occurs. As such, it can be difficult to quantify the magnitude and degree of nuisance impact of wood smoke odours in a community.

No studies documenting evidence of property damage or odour concerns were identified in the literature. While particulate (dust) fall out does occur, the amounts are expected to be minor in comparison to other sources of dust across the region (e.g., roads, fields, etc.). However, buildings and property in close proximity to wood burning appliance chimneys can result in localized soiling. In contrast, a review of complaint data provided by Metro Vancouver shows that odour due to wood burning can be an issue. While some of these complaints are likely due to burning of yard waste/trash, residential wood smoke emissions are also expected to lead to elevated odour levels, at least occasionally. These are expected to be more localized in areas where wood burning is more prevalent and are also likely dependant on meteorological conditions. In addition, issues related to elevated odour levels are more extensive in more densely populated areas.

[1] One odour unit is the level at which 50% of people can smell an odour and 50% of people are unable to smell the same odour.

Impact on Vendors

The economic impact on wood burning device vendors and wood fuel suppliers is difficult to quantify. Many of these vendors and suppliers are thought to be family operated or small business. The loss of customers may have a large impact on income to these individuals and business.

1.4 POLLUTANTS CONSIDERED

Wood smoke is a complex mixture of many different chemicals that can adversely affect human health including fine particulate matter ($PM_{2.5}$), coarse particulate matter (PM_{10}), sulphur oxides, nitrogen oxides, carbon monoxide, volatile organic compounds (VOCs) and other toxic or carcinogenic compounds such as benzene, formaldehyde and polycyclic aromatic hydrocarbons (PAHs). Many of the compounds present in tobacco smoke are also present in residential wood smoke. While the health effects associated with many substances in wood smoke have been well characterized, there is little information on the health effects of wood smoke itself as a complex mixture of substances.

To evaluate potential health effects associated with exposure to residential wood smoke, this study focused on $PM_{2.5}$. This was done because a review of the literature indicated that $PM_{2.5}$ is released in higher amounts than other toxic substances and $PM_{2.5}$ exposure is associated with a wide variety of adverse health effects. A very good comprehensive review of the health effects associated with wood smoke exposure is provided by Naeher et al. (2007). Importantly, the health benefits associated with a decrease in $PM_{2.5}$ exposure can be quantified with a reasonable degree of certainty.

As described later in the report, there will be other health benefits associated with wood smoke emission reductions that have not been quantified because of insufficient information and/or study constraints. Nevertheless, these unquantifiable benefits will be realized.

1.5 SUB-REGIONAL CONSIDERATIONS

Residential wood smoke emissions and ambient $PM_{2.5}$ concentrations can vary locally based on a number of factors including age of housing stock, household income, proximity and availability of wood, geography and meteorology, among others. This can result in different pollutant exposure levels by individuals depending upon where they live. While these differences were recognized qualitatively, it was beyond the scope of this study to conduct a quantitative analysis on a sub-regional level. Furthermore, there is insufficient information on sub-regional use of residential wood burning appliances.

2.0 HEALTH AND ECONOMIC PROFILE OF THE METRO VANCOUVER REGION

This section presents an overview of health and well-being in Metro Vancouver. The indicators presented are those that are relevant to understanding the potential effects of current or future residential wood burning in the region.

Metro Vancouver is comprised of 23 local authorities, including 21 municipalities, one treaty First Nation, and one electoral area. Although the region is urban – with a current population of 2.3 million people and counting – only a third of its total area of 2,865 square kilometres is designated as such; the remaining two-thirds of the land is made up of forests, alpine areas, wetlands, marshes, streams, rivers, estuaries, and agricultural lands.

The different communities in the Metro Vancouver region each have unique characteristics. It is important to note that health is not homogenous across the region; some of the communities within Metro Vancouver tend to be substantially better off, on average, than others when measured in terms of either health or economic outcomes.

2.1 HEALTH OUTCOMES

The *My Health My Community Survey*, a study that was conducted among adults across the Metro Vancouver region, reports rates of hypertension and heart disease for different age groups in the Metro Vancouver region. The results are shown in **Table 1** and provides information on the population distribution among different age groups in the Vancouver census metropolitan area.

Table 1 Prevalence of Hypertension and Heart Disease in Metro Vancouver By Age

Age Group	Hypertension	Heart Disease
Ages 18-39	4%	1%
Ages 40-64	20%	4%
Ages 65+	43%	16%

Source: My Health My Community Survey

A number of health conditions that can be exacerbated by $PM_{2.5}$ exposure including chronic breathing conditions, heart disease and high blood pressure, are depicted in **Table 2**. These conditions often vary by age group, with older ages having higher prevalence of these diseases.

Table 2 presents data that relates to health outcomes across the Metro Vancouver region. The first row in the table shows the percent of the population that rated their own health as ‘very good’ or ‘excellent’. Self-rated health is one of the strongest and most consistent predictors of subsequent illness and premature death (Idler and Benyamini 1997) and is therefore a strong proxy for both current and future overall health status.

As shown in the table, on average, 48.5% of people in the Metro Vancouver region who participated in the *My Health My Community Survey* rated their health as very good or excellent. Self-reported health in the Metro Vancouver region has been found to be slightly higher compared to BC as a whole or to Canada. The Canadian Community Health Survey found that 60.7% of people in the Vancouver Census Metropolitan Area (CMA) reported very good/excellent self-rated health compared with 59.9% for BC as a whole, and 59.9% for a Canadian average (Statistics Canada, 2013).

A number of communities have a substantially higher percentage of people with very good/excellent self-rated health than the Metro Vancouver average, including the District of West Vancouver and Village of Lions Bay, the North Shore, the District of North Vancouver, Port Moody, Bowen Island, the City of North Vancouver, South Surrey and White Rock. This high level of health is reflected in other indicators, with these communities tending to have better-than-average rates of mental health, physical activity and overall physical wellness, and lower-than-average rates of obesity, diabetes, chronic breathing conditions, and multiple chronic conditions.

Conversely, a number of communities have lower-than-average rates of self-rated very good/excellent health, including the City of Langley, Richmond, Maple Ridge, Pitt Meadows and Surrey. Unsurprisingly, a number of other health conditions tend to have a higher prevalence in these communities, including diabetes, overall physical wellness, cancer and high blood pressure.

A number of health conditions that can be exacerbated by fine particulate matter exposure – including chronic breathing conditions, heart disease and high blood pressure – also show variance across the Metro Vancouver region. However, these conditions do not appear to be related to overall health status in this instance.

2.2 ECONOMIC AND SOCIAL WELL-BEING

Economic well-being is also not homogenously distributed across the Metro Vancouver region, as shown in **Table 3**. Three indicators are presented in the table that correspond to different measures of economic difficulty: household income under $40,000, current unemployment and food insecurity.

The communities of Port Moody, Port Coquitlam, South Surrey and White Rock, Township of Langley, District of North Vancouver, Coquitlam, Delta, Bowen Island, Maple Ridge, District of West Vancouver and Village of Lions Bay, and North Shore had the highest rates of household income under $40,000 and similarly high rates of current unemployment and food insecurity.

Communities that had stronger economic indicators included Surrey, Richmond, Vancouver, the City of Langley, the City of North Vancouver and Burnaby.

As with health status, economic well-being is not uniform within any of these communities, and every community has a mix of people who are very well-off and those who have high levels of need.

Finally, community belonging describes social attachment of individuals to their communities, and represents an "upstream" approach to preventing illness and promoting health (Statistics Canada, 2016). As shown in **Table 3**, there is a wide variation among communities of the percentage of the population that reported having a ‘strong’ or ‘somewhat strong’ sense of community belonging.

Table 2 Indicators of Physical and Mental Health in Metro Vancouver

	Metro Vancouver	Bowen Island	Burnaby	City of Langley	City of North Vancouver	Coquitlam	Delta	District of North Vancouver	District of West Vancouver and Village of Lions Bay	Maple Ridge	New Westminster	North Shore	Pitt Meadows	Port Coquitlam	Port Moody	Richmond	Surrey	South Surrey and White Rock	Township of Langley	Vancouver
General health (excellent/very good) (%)	48.5	54.8	46.2	40.7	54.6	52.1	51.0	59.5	68.2	43.3	46.0	60.1	45.3	46.9	58.9	41.5	45.5	54.4	50.1	50.0
Mental health (excellent/very good) (%)	56.5	62.4	54.0	55.9	58.7	59.2	61.6	65.0	71.0	51.7	57.1	64.6	47.7	58.1	63.0	52.4	59.6	67.7	62.7	52.2
Obesity (BMI 30+) (%)	21.7	22.8	19.2	35.8	21.1	21.0	26.6	20.0	19.0	32.8	26.8	20.1	31.1	31.6	17.3	16.9	28.1	21.7	29.0	15.2
Diabetes (%)	7.7	6.1	6.0	9.5	6.9	6.0	9.8	3.9	5.4	8.3	10.8	5.2	s	5.0	s	8.4	11.5	7.3	6.3	6.5
High blood pressure (%)	17.9	20.1	18.9	18.5	15.3	14.9	21.0	17.1	23.5	19.5	19.2	18.1	17.7	22.2	18.7	20.2	20.6	23.3	14.4	14.5
Heart disease (%)	4.7	5.3	5.4	s	3.5	2.8	7.2	3.1	5.7	5.0	4.7	3.9	s	s	s	4.7	5.7	6.3	7.6	3.8
Chronic breathing condition (%)	7.2	10.1	7.1	9.4	10.2	6.1	7.4	6.4	4.0	7.8	7.9	7.0	4.1	8.3	6.7	6.2	6.7	5.5	8.4	7.7
Arthritis (%)	13.1	14.7	12.9	19.7	13.2	10.7	16.7	13.2	18.1	15.8	13.6	14.4	7.4	14.1	9.5	12.1	13.8	17.6	13.7	11.6
Mood or anxiety disorder (%)	16.3	17.2	13.9	24.3	19.9	13.9	15.5	12.8	12.3	25.8	20.7	14.8	18.2	17.5	17.7	11.3	15.2	13.3	15.1	18.5
Multiple chronic conditions (%)	7.9	6.9	8.5	8.7	7.6	6.2	10.7	5.8	7.4	7.1	8.9	6.7	6.1	5.9	s	8.6	10.3	10.3	8.5	6.3
Cancer (lung, breast, prostate or colorectal) (%)	2.9	4.8	2.6	s	3.0	2.7	2.8	4.2	5.7	2.8	3.2	4.6	s	s	s	3.1	3.0	5.0	2.8	2.5
Smoker (daily/occasional) (%)	10.6	11.1	8.7	18.3	13.0	11.7	8.7	6.8	6.2	14.2	14.5	8.4	7.9	10.0	3.3	7.8	11.2	5.8	8.2	12.1
Physical activity (150+ minutes/week) (%)	44.1	57.3	40.1	40.9	48.9	38.2	46.0	54.8	57.8	47.2	44.7	53.9	43.3	47.2	56.7	37.5	41.3	47.6	48.8	45.9
High physical wellness score (10-16) (%)	37.7	42.8	35.5	28.4	38.6	31.6	34.6	44.7	46.9	32.4	39.4	43.6	36.5	35.1	43.9	36.8	35.3	37.8	35.2	40.9

Source: My Health My Community Survey as of August 2014. Prepared by: Vancouver Coastal Health, Public Health Surveillance Unit, September 2015.
S = supressed due to small sample of respondents.

Table 3 Indicators of Economic and Social Well-being in Metro Vancouver

	Metro Vancouver	Bowen Island	Burnaby	City of Langley	City of North Vancouver	Coquitlam	Delta	District of North Vancouver	District of West Vancouver and Village of Lions Bay	Maple Ridge	New Westminster	North Shore	Pitt Meadows	Port Coquitlam	Port Moody	Richmond	Surrey	South Surrey and White Rock	Township of Langley	Vancouver
Household income under $40,000 (%)	31.7	23.5	34.2	37.4	35.3	20.9	21.6	18.6	24.9	23.8	31.5	25.0	s	14.8	6.9	38.5	33.4	16.4	18.1	38.2
Currently unemployed (%)	6.4	s	5.5	7.7	9.5	4.1	6.1	3.4	4.2	6.1	8.8	5.3	s	4.0	s	6.7	7.8	2.4	3.4	7.3
Food insecure (sometimes/often) (%)	7.0	s	5.7	5.9	8.5	4.6	3.6	4.3	s	12.3	10.2	5.1	s	s	s	6.3	7.4	2.8	6.9	8.5
Community belonging (strong/somewhat strong) (%)	55.9	82.2	49.1	55.4	63.7	53.0	69.4	66.6	74.1	56.3	60.4	67.9	64.1	56.2	60.6	56.2	53.6	62.4	56.8	53.8

Source: My Health My Community Survey as of August 2014. Prepared by: Vancouver Coastal Health, Public Health Surveillance Unit, September 2015.
S = supressed due to small sample of respondents.

2.3 Vulnerable Groups

Although **Table 2** shows distinctions in health status by community, it is important to bear in mind that the data presented are averages, and that not all people within a given community have the same health status.

Vulnerable populations comprise those people who are more likely than others to suffer adverse health effects. Biological factors (e.g., age), social constructs (e.g., gender, ethnicity), material conditions (e.g., employment, income), or exposure to harmful environments can all contribute to the vulnerability of a particular group (Ross et al., 2014).

Vulnerable populations in the Canadian context often include Aboriginal peoples, people living in poverty, immigrants and refugees, people with disabilities, people who are gender and sexually diverse, people experiencing homelessness or lack of affordable housing, people with low literacy skills, and people living in poor, rural or remote communities (Alberta Health Services, 2011).

Certain groups are more likely than others to experience adverse health effects from a given exposure to the airborne contaminants found in wood smoke. These include children, the elderly, those with pre-existing cardiovascular or respiratory disease, and those with low socio-economic status (Sacks et al., 2011). Some data on the prevalence of existing cardiovascular and respiratory disease across the Metro Vancouver region is provided in **Table 1** and **Table 2**, and data on socio-economic status is provided in **Table 3**. **Table 4** provides information on the population distribution among different age groups in the Vancouver census metropolitan area. As shown in the table, over 825,000 people, representing almost one-third of the population, were either under the age of 18 or over the age of 65.

Table 4 Population Distribution by Age Across Metro Vancouver

Age Group	Number of People	Percent of Population
Ages 0-17	448,092	17.8%
Ages 18-64	1,687,051	67.1%
Ages 65 and over	378,713	15.1%

Source: http://www.bcstats.gov.bc.ca/StatisticsBySubject/Demography/PopulationEstimates.aspx.

2.4 Health Care Services

Health care in B.C. is provided through the B.C. Ministry of Health, which organizes service delivery through six health authorities. The Metro Vancouver region spans two health authorities: The Vancouver Coastal Health and the Fraser Health Authority. The First Nations Health Authority assumed responsibility for the health and well-being of First Nations people in the province in 2013, making it their goal to successfully address health disparities between First Nations and non-First Nations communities in B.C. through collaboration and coordination with the Ministry of Health and Regional Health Authorities.

3.0 RESIDENTIAL WOOD BURNING IN METRO VANCOUVER

3.1 RESIDENTIAL WOOD BURNING APPLIANCE USE

Currently, there is little published information on the number of residential wood-burning appliances in use in Metro Vancouver. While anecdotal information from discussions with Metro Vancouver staff helped to inform the study, a published report by the BC MOE (2012) provides data from five different surveys completed in BC that describe residential wood burning appliances and related behavior. Pertinent excerpts from this study are presented below.

> *"Based on the data from the surveys, the use of wood for heating in BC has not changed much between 2003 and 2012 and remains stable at about 31%. Wood use per household has also remained stable (except for MV). On the other hand, a clear trend towards more certified appliances can be observed: 68% of all wood stoves were certified for low emissions in 2012 (44% in 2003), and about half the fireplaces (inserts) were certified in 2012. This trend towards cleaner burning appliances is confirmed by the average age of wood stoves, which appears to have fallen from around 18 years in 2003 to around 17 years in 2012 (not including MV, where appliance age appears to have increased). At the same time, there is a trend away from fireplaces and inserts towards certified wood stoves, pellet stoves, and central heating systems, which are generally cleaner burning appliances. This can be expected to lead to lower air emissions, which is also reflected in the overall improvement of attitudes about wood smoke throughout BC.*
>
> *These expectations are, however, not reflected in the emission results, which show an increase of residential wood combustion emissions since 2003. The increase can be explained based on the large increase in wood use in Metro Vancouver and the FVRD[2], which is likely not real but due to a major change in methodology between 2003 and 2012 (we believe the 2010 data are more reliable and the 2002 survey may have underestimated wood use in MV). Yet, a decrease since 2003 would be expected due to the larger number of certified appliances in 2012. It is believed that the discrepancy also stems from great local variation in wood user incidence determined from the 2003 and 2012 datasets. Without corroboration from other sources, such as wood stove sales statistics, it remains unclear whether these variations are real or only statistical artefacts. The results should therefore not be taken as ultimate proof that emissions have not decreased since 2003 but it is more likely that firm conclusions cannot be drawn based on the data at hand."*

[2] Fraser Valley Regional District

Figures 2 through **Figure 6** below were reproduced from the BC MOE (2012) report and present information on wood use, and people's behaviour and opinions on residential wood burning. For Metro Vancouver, the data indicate that there is a higher prevalence of use of fireplaces (natural or insert) compared with other regions. Because of the lower efficiency of fireplaces compared with other wood burning appliances, this suggests that as a whole, more people in the region burn wood for aesthetic reasons rather than residential heating.

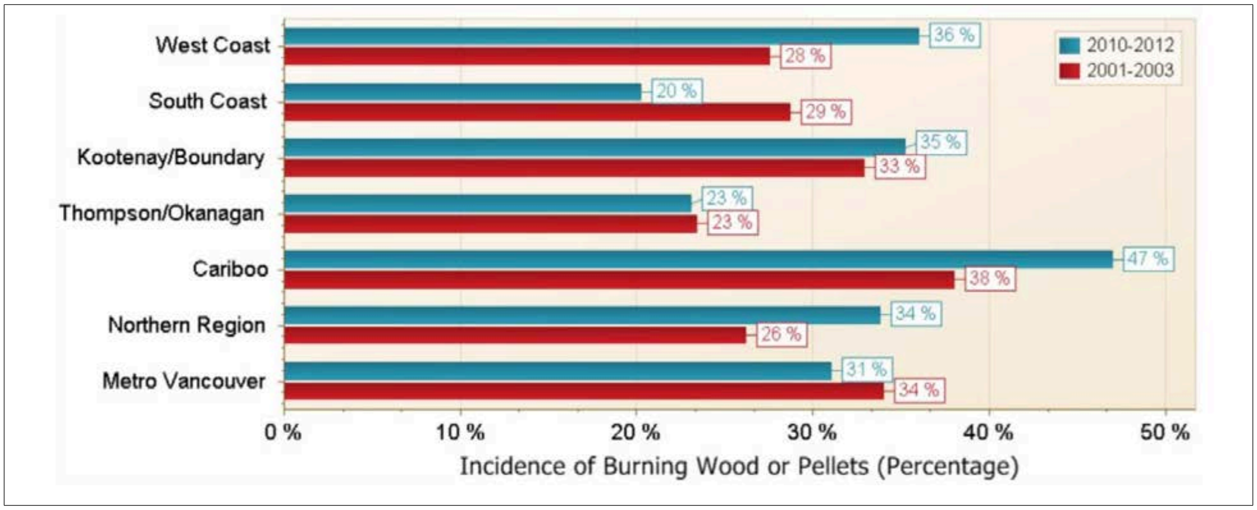

Figure 2 Percentage of Wood Users, by Region (2003 and 2012)

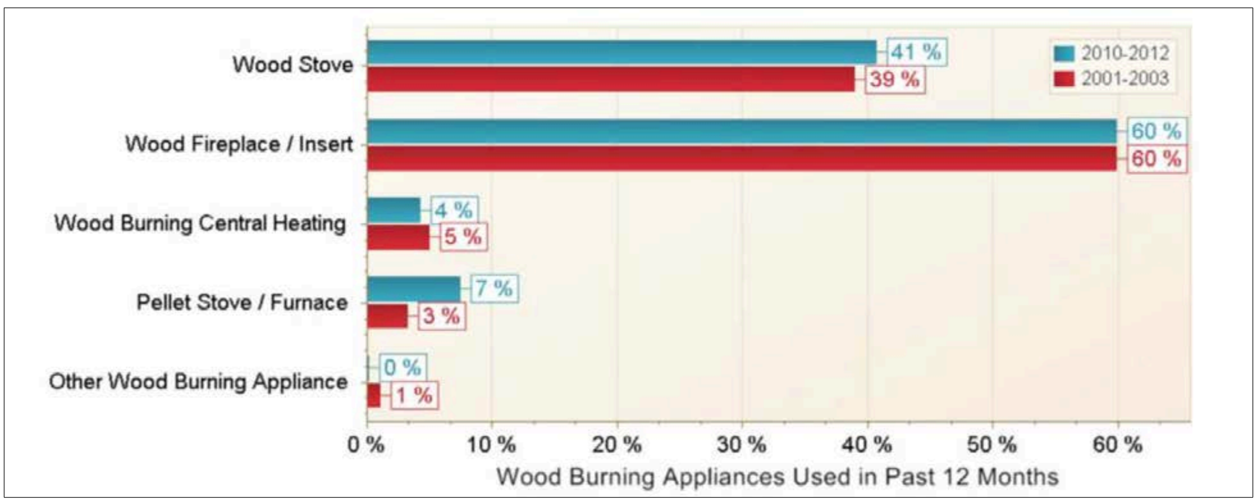

Figure 3 Wood Burning Appliance Types

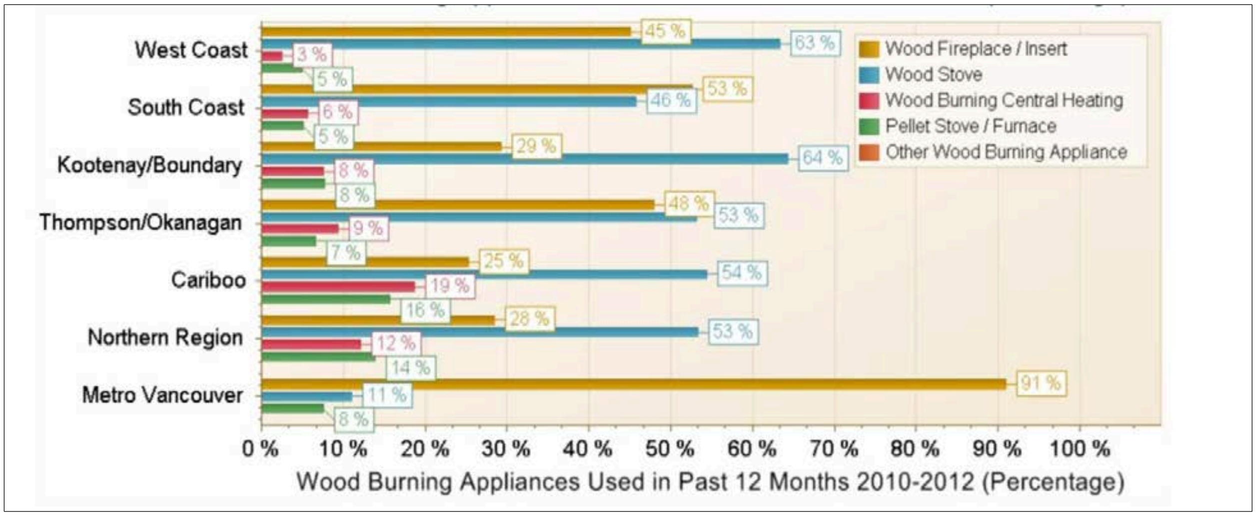

Figure 4 Wood Burning Appliances by Region (2012)

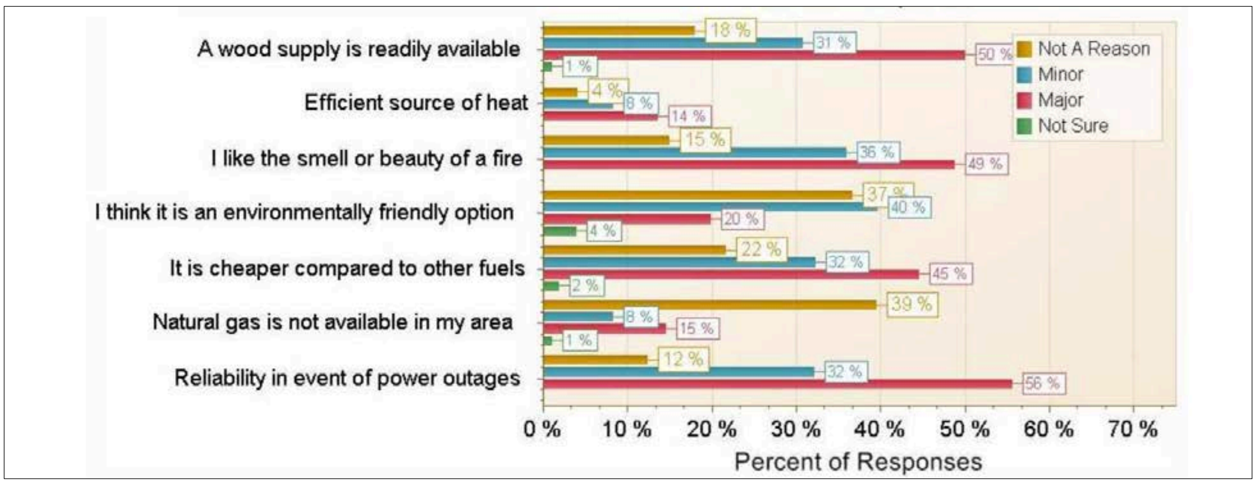

Figure 5 Reasons for Wood Burning (2012)

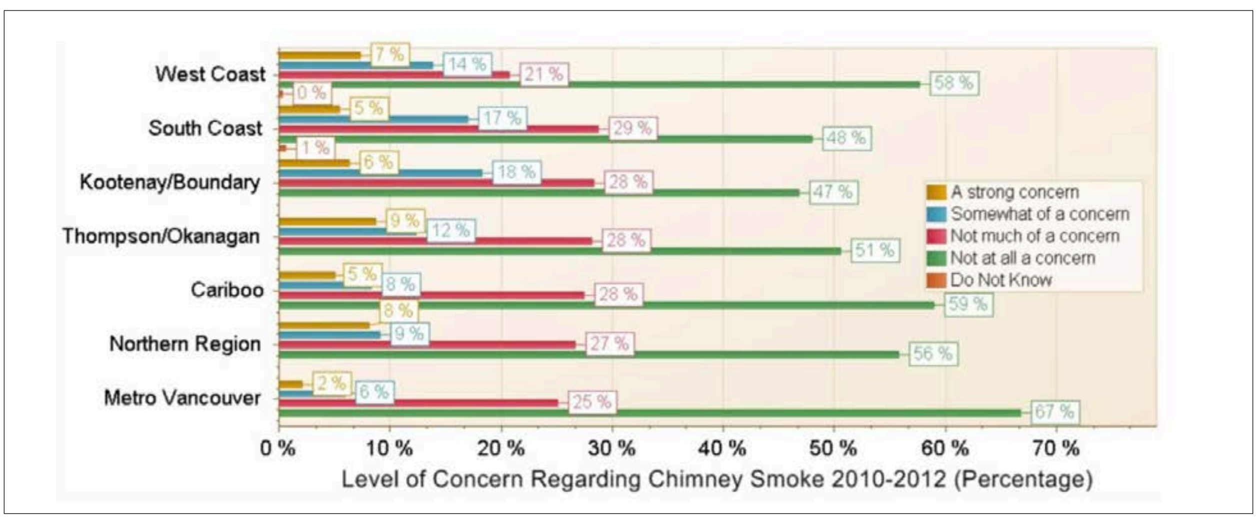

Figure 6 Wood Smoke Concerns, by Region

From the BC MOE (2012) study, the total estimated emissions of pollutants for the year 2012 is provided in **Table 5**. Compared with other regions of the province, pollutant emissions from residential wood burning appliances in Metro Vancouver are about three times higher. While this obviously is due to the much larger population in the region, it nevertheless indicates that emissions are significant and can potentially impair air quality within the region and, more importantly, in certain areas/communities that rely more heavily on wood burning. Because of the greater population, there are more people who are exposed to emissions from residential wood burning appliances.

Table 5 Wood Burning Appliance Emissions in 2012, by Region and Sub-Region (tonnes)

Region	CO	NOx	SOx	VOC	PM_{10}	$PM_{2.5}$
Central	3,069	59	8	615	635	633
Northeast	1,294	25	4	268	260	259
South of Fraser	4,135	78	11	874	873	870
North Shore	1,121	21	3	235	238	238
Metro Vancouver Total	**9,619**	**183**	**26**	**1,992**	**2,006**	**2,000**

3.2 CONTRIBUTION OF RESIDENTIAL WOOD BURNING TO AMBIENT $PM_{2.5}$ LEVELS IN METRO VANCOUVER

Surveys of $PM_{2.5}$ emission sources within the Lower Fraser Valley combined with $PM_{2.5}$ speciation data suggests that residential wood burning contributes up to 35% of the ambient $PM_{2.5}$ concentrations measured during the wood burning season (i.e., the 6-month period from October to March) (Fine et al. 2002; Ries et al. 2009; and Julie Saxton, Personal Communication November 2016). The contribution of residential wood burning was dependent on location but was also limited by the availability of data characterizing ambient $PM_{2.5}$ concentrations in air. That is, areas within Metro Vancouver that are associated with higher wood burning activities may not be covered by existing air quality monitoring stations. In general, the residential wood burning contribution to ambient $PM_{2.5}$ concentrations was estimated to range between 6% to 17% within urban areas of Metro Vancouver and between 15% to 35% within rural areas of Metro Vancouver. These are consistent with the estimate that approximately 27% of $PM_{2.5}$ emissions across the region are due to residential wood burning (Metro Vancouver 2014).

4.0 POTENTIAL POLICY OPTIONS

4.1 POLICY INITIATIVES FROM SELECT JURISDICTIONS

A review of residential wood burning appliance programs was undertaken to help inform the development of potential policies for Metro Vancouver. Programs were evaluated based on their relevance to Metro Vancouver including similar geography, meteorological and weather conditions and demography. Of the programs reviewed, the Puget Sound Clean Air Agency (PSCAA) Wood Smoke Reduction Initiative was considered to be the most appropriate program to highlight. The key aspects of this program have been described by Boyle et al. (2013) and Strange and Weiss (2013) and are summarized below.

Wood stoves, fireplaces, and other solid fuel burning devices sold in Washington State must be certified to meet Washington state emission standards. During times of impaired air quality, the PSCAA issues county-wide burn bans. A burn ban is a mandatory, yet temporary, order that restricts the use of wood stoves and fireplaces for communities that have $PM_{2.5}$ concentrations above federal standards. There are two types of burn ban stages that can be issued:

- Stage 1 - During a Stage 1 burn ban ($PM_{2.5}$ concentrations exceed 25 $\mu g/m^3$, 24-hour average), no burning is allowed in fireplaces and uncertified wood stoves, unless it is the household's only adequate source of heat and they have an approved exemption from the agency. Households can use pellet stoves, EPA[3]-certified wood stoves and natural gas or propane fireplaces.
- Stage 2 - During a Stage 2 burn ban ($PM_{2.5}$ concentrations exceed 35 $\mu g/m^3$, 24-hour average), no burning is allowed in any fireplace, pellet stove or wood stove (certified or not), unless it is the household's only adequate source of heat and they have an approved exemption from the Agency. Households can use natural gas or propane fireplaces.

Regardless of the stage, no visible smoke is allowed and all outdoor burning is prohibited during a burn ban, even in areas where otherwise permitted by law.

The PSCAA estimates the number of burn ban days each year to be approximately fifteen Stage 1 days and three to five Stage 2 days. Non-compliance with the burn bans can result in a $1,000 (USD) violation fee for each occurrence.

In the lead up to the ban on uncertified wood stoves, the PSCAA enacted a wood stove replacement program designed to assist residents in removing, replacing or recycling old, uncertified wood stoves with cleaner, more efficient heating devices. This consisted of the following:

- Wood stove buy-back program: Households received up to $350 USD by turning in their old, uncertified wood stove ($200 USD if the agency picks up the stove).

[3] Environmental Protection Agency

- No-cost replacement program: Low-income households (defined as having household income up to 150% of the federal poverty level or $35,325 USD for a family of four) with a wood stove manufactured before 1995 could receive a replacement device for no cost.
- Replacement lottery (full cost award and point-of sale discounts): Two lotteries were held for non-low-income households and ten grand prizes (free replacements) were awarded. All other non-low-income households that entered the lottery received $1,000 and $1,500 USD point-of-sale discounts to use when replacing old stoves/inserts with certified heating devices.

The effectiveness of incentives for residents to switch from older, higher emitting wood burning devices to newer, more efficient devices is mixed. It is estimated that the PSCAA replacement program was able to eliminate about 6% of old uncertified wood burning devices.

The BC MOE has developed a similar replacement program[4]. A review of this program found that between 2008 and 2014 over 6,000 uncertified wood stoves were replaced at an estimated cost to the province of approximately $2.2 million or $370 per stove (Pinna Sustainability 2015). While encouraging, the report notes that there has not been a clear reduction in $PM_{2.5}$ levels which may partially be explained by increased residential wood burning and poor burning practices (e.g., using unseasoned wood). The authors also note that low income families may not be able to access the incentive program because the incentive offered are not enough to offset the cost of installing a new certified stove (Pinna Sustainability 2015).

Metro Vancouver also has a wood burning appliance exchange program which offers a $250 rebate towards the purchase of a new low emission appliance. Since 2009, over 300 high-emitting wood stoves and open-hearth fireplaces have been switched out with low emitting appliances or natural gas appliances and this has reduced $PM_{2.5}$ emissions by about 5,500 kilograms per year (Metro Vancouver 2014). In addition to rebates, Metro Vancouver provides education and public outreach materials to raise awareness of the program and increase participation.

Environment Canada (2006) describes various control strategies and options that can be incorporated into municipal by-laws that have and can be used to regulate wood burning appliances. The three main types of strategies include limits on emissions, financial assistance strategies to encourage the use of certified appliances and education and outreach to inform the public of the need to reduce emissions. These have been developed into the following types of by-laws:

- Restrictions on some fuels to encourage the use of seasoned wood.
- Requirement for installation of certified appliances only (± some exceptions).
- Change-out programs to encourage switching to certified appliances.
- No burn days (voluntary, mandatory, mandatory with some exceptions).
- Requirement not to cause odour or reduce visibility (smoke out).

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[4] http://www.bcairquality.ca/topics/wood-stove-exchange-program/

One key element of all the programs investigated is public outreach and education programs, which are absolutely required for successful implementation of any residential wood smoke reduction programs. These programs need to highlight the association between residential wood smoke emissions, ambient air quality and health. Information on cost savings (i.e., pay back period) that may be realized with using high efficiency certified appliances can also be helpful, especially if there are replacement incentives available.

Regulatory initiatives in Smithers and Port Alberni, British Columbia and Montreal, Quebec have been implemented and incorporate aspects of the program elements described above. Since these programs have recently been implemented, there are no data yet available to assess their effectiveness.

4.2 INPUT FROM HEALTH AUTHORITIES AND LOCAL EXPERTS

To help inform the current study and identify key issues that need to be considered as part of any policy restricting residential wood burning, experts from the local health authorities and universities were consulted and asked to provide input on local context and advice on methodologies, resources, policies decisions/implementation and socio-economic effects. A summary of the feedback received from the experts is provided in **Appendix B**. The following key points were identified:

- The evaluation needs to consider both benefits to health due to reduced pollutant exposure, together with the potential for unintended negative socio-economic effects that might arise. It was noted that socio-economic status plays a larger role in health than does exposure to pollutants in ambient air.
- Some experts questioned the need for developing a broad regulation for all of Metro Vancouver for an issue that is considered to be more of a localized problem in areas where residential wood burning is common.
- It is appropriate to focus on effects related to $PM_{2.5}$ exposure. However, AQBAT[5] does include recent studies on acute exposure looking at asthma days and restricted activity days, as well as some more recent information on chronic effects. Concern was also raised regarding the cost of mortality estimates in AQBAT would overshadow acute health effects that directly affect day-to-day wellness.
- Successful implementation of a wood smoke regulation program must be done in concert with public outreach and education programs to increase awareness. There is a perception among the public that emissions caused by wood smoke are not as bad as those from other sources. Odour can be an issue in some neighbourhoods and can alter behaviour.
- Limitations and uncertainties associated with the study need to be presented to provide context and help inform discussion on the pros and cons of a policy vis-à-vis the socio-economic determinants of health.

5 Air Quality Benefits Assessment Tool; developed by Health Canada

4.3 Scenarios Resulting in $PM_{2.5}$ Reductions

Two policy options to reduce wood smoke emissions from residential wood burning appliances have been considered in this study. The key elements of these policies are summarized below.

4.3.1 Emission Standards for all Wood Burning Appliances – Potential Policy Option 1

This policy would require indoor wood burning appliances that do not meet emissions standards not be used or replaced with advanced low emission appliances that meet defined emission standards and/or approved certification such as the New Source Performance Standard (NSPS) adopted by the US Environmental Protection Agency (EPA 2015) or other acceptable certification, as described by the Canadian Council of Ministers of the Environment (CCME 2012).

Indoor appliances that use wood as a source of fuel include wood stoves, pellet stoves, fireplaces, conventional fireplaces, advanced technology fireplaces, fireplace inserts, wood cook stoves, masonry heaters, central heating furnaces and boilers (CCME 2012). Conventional wood burning appliances include those that are generally inefficient at producing heat from wood fuel and emit higher amounts of $PM_{2.5}$ as a result. There are a range of these wood burning appliances in use within Metro Vancouver (BC MOE 2012) and Ipsos Reid 2010[6].

It is estimated that conventional fireplaces and uncertified woodstoves contributed approximately 85% to the $PM_{2.5}$ emissions associated with residential wood burning within Metro Vancouver. By comparison, certified woodstoves contributed <1% to $PM_{2.5}$ emissions in Metro Vancouver (Julie Saxton, Personal Communication November 2016). Removing conventional fireplaces and uncertified woodstoves or replacing these appliances with certified woodstoves could therefore substantially reduce $PM_{2.5}$ emissions associated with residential wood burning in Metro Vancouver.

4.3.2 Emission Standards for Wood Burning Appliances with Some Exemptions – Potential Policy Option 2

This policy is exactly the same as that described above in terms of the replacement or refrain from using conventional wood heating devices; however, there is flexibility with this policy to allow for the exemption of low-income households where conventional wood heating devices are the primary source of heat.

Knowing that 31.7% of the households in Metro Vancouver are low income (Vancouver Coastal Health 2015) and assuming that 31% of these households use wood for heating purposes (Envirochem 2012), it was assumed that approximately 10% (i.e., 31% of 31.7%) of the population would be exempt from a policy to replace conventional wood heating devices. This exemption was assumed to result in a 10% reduction in the participation/compliance rate compared with the first policy option (i.e., from 53% to 43%). The 10% reduction was used in the AQBAT modelling to estimate the upper limit of the possible impact that such a policy would have.

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6 Unpublished survey regarding residential wood burning in Metro Vancouver.

4.3.3 Policy Compliance

The success of this initiative is conditional on acceptance of the policy by users of conventional wood heating devices who will need to make the necessary changes to replace or refrain from using non-certified devices. Acceptance of a policy is more likely when there is an understanding of the association between the policy and improvements in air quality and human health (particularly for vulnerable individuals with existing respiratory conditions such as asthma or bronchitis).

The 2010 Ipsos Reid survey for Metro Vancouver on the use and attitudes of residents of Metro Vancouver towards residential wood burning devices determined that 65% of those with a wood burning device support restricting the operation of devices that are not certified and 41% of those with a wood burning device are likely to consider converting to cleaner technology. A report by Envirochem (2012) provided the results of five surveys of residential wood burning appliances and use for BC since the year 2000. In the latest survey (2012), 26% of respondents were very or somewhat likely to install new wood burning equipment in the next two to three years. There was more support from respondents for a cash-back incentive program to replace old stoves rather than the implementation of a bylaw to reduce wood smoke.

A recent research project in Upper Hunter, New South Wales (Australia) specifically surveyed wood heater user attitudes towards the effects of wood smoke on ambient air quality and health (Databuild Research & Solutions, 2016). In the region under study, wood represents a free or low-cost alternative to electricity or gas. The focus of the study was to identify whether owners of wood heaters were aware of the health risks associated with exposure to wood smoke and gauge their willingness to upgrade their heating options. If directly asked to switch to a different form of heating, the majority of respondents were not willing (96%) even if a discount was offered for the replacement of the wood heater (89%).

The attitudes of the wood heater users towards wood smoke and health effects were further explored. The study divided respondents into four segments including: oblivious (35% did not understand that wood smoke is harmful to human health); rejecters (19% did not accept that wood smoke is harmful to human health); rationalizers (28% considered wood smoke to cause no more harm to human health than other industrial sources of particle pollution in the region), and; conditional accepters (18% were prepared to listen and possibly change their behaviour if change was not onerous).

The results of this study suggest that the oblivious and the conditional acceptors, which represent 53% of respondents, could be prepared to accept that wood smoke emissions are impacting air quality and human health, once this information was disseminated and understood. This compliance rate (53%) also represents the mean value between those in Metro Vancouver who support restricting the operation of uncertified wood burning devices (65%) and those with a wood burning device that would consider converting to cleaner technology (41%) as summarized by the Ipsos Reid survey.

5.0 ESTIMATED BENEFITS OF POLICY OPTIONS

To quantify improvements in community health and the value (benefit) of reducing the incidence of adverse health outcomes as a result of policies to remove or replace uncertified wood heating devices within Metro Vancouver, the Health Canada "Air Quality Benefit Assessment Tool" (AQBAT, Version 2.0) model was used.

5.1 OVERVIEW OF AQBAT

AQBAT is a modelling tool that was developed by epidemiologists and statisticians within Health Canada to allow for the assessment of the health and economic benefits associated with an improvement (i.e., reduction) in air pollutant(s) concentration. Specifically, benefits are predicted for populations within Canada as a whole, within a Canadian province or territory, or within a Canadian census division (CD). For this study, the Metro Vancouver region represented by Statistics Canada CD 5915 was evaluated.

Scenario years are the year(s) for which health benefits are estimated as a result of a defined change(s) in pollutant concentrations. A forecast scenario provides estimates for a scenario in the future, including projected population data based on defined growth trends. The future scenario is compared to baseline information, including measured air concentrations and reported health effects associated with the pollutant under investigation. Baseline air quality data for AQBAT is provided by the National Air Pollution Surveillance (NAPS) program of Environment Canada for the years 1997 through to 2008. Improvements in ambient air quality are evaluated against the NAPS baseline data (e.g., from 2005 to 2008 for 24-hour $PM_{2.5}$ concentrations).

The health endpoints associated with acute and chronic exposure to $PM_{2.5}$ modelled in AQBAT are as follows:

<u>Acute Health Effects</u>

- Acute Respiratory Symptom Days (non-asthmatics, all ages);
- Asthma Symptom Days (all ages);
- Cardiac Emergency Room Visits (all ages);
- Cardiac Hospital Admissions (all ages);
- Child (<20 years) Acute Bronchitis Episodes;
- Elderly (>65 years) Cardiac Hospital Admissions;
- Respiratory Emergency Room Visits (all ages);
- Respiratory Hospital Admissions (all ages); and
- Restricted Activity Days (non-asthmatics >20 years).

Chronic Health Endpoints

- Adult (>25 years) Chronic Bronchitis Cases;
- Chronic Exposure Mortality (>30 years);
- Chronic Exposure Respiratory Mortality (>30 years);
- Chronic Exposure Cerebrovascular Mortality (>30 years);
- Chronic Exposure Ischemic Heart Disease Mortality (>30 years); and
- Chronic Exposure Lung Cancer Mortality (>30 years).

Each of these health endpoints is represented by a Concentration Response Function (CRF) which is used by the model to provide a quantitative estimate of the effects of $PM_{2.5}$ exposures on human health. The CRFs are developed based on epidemiological studies reviewed and endorsed for relevance to the Canadian population by Health Canada. Baseline occurrences of health endpoints identified in AQBAT are derived from estimated annual events for every possible geographic area, age group, scenario year and population projection (future scenarios).

An endpoint valuation (EPV), representing the monetary value of the health endpoint (e.g., the cost of cardiac hospital admission) is assigned to each CRF. The valuations for health endpoints are endorsed by Health Canada and considered relevant to the Canadian population as a whole.

To account for inherent variability when modelling health outcomes within a population, each of the data inputs (baseline and projected future pollutant concentrations, baseline and projected populations, CRFs and EPVs) are assigned a probability distribution. Statistical software (@Risk) is then used to perform Monte Carlo simulations, which involves sampling from each of the input distributions and tracking outputs (results). Descriptive statistics are provided for the distributions of the output/results, which detail the health and economic benefits.

The current assessment focused on the reduction in the number of health endpoint occurrences (count) and monetary savings (valuation) associated with a decrease in ambient $PM_{2.5}$ concentrations for each of the proposed wood burning policy options.

5.2 AQBAT Model Assumptions

The removal/replacement of conventional fireplaces and uncertified woodstoves was predicted to result in an 85% reduction in $PM_{2.5}$ emissions associated with residential wood burning in Metro Vancouver. The contribution of residential wood burning to $PM_{2.5}$ concentrations in ambient air was assumed to be 15% (for urban areas) or 35% (for rural areas) based on the contribution of wood burning to $PM_{2.5}$ from studies conducted by Metro Vancouver. A compliance/participation rate of 53% was assumed for potential Policy Option 1 (no exemptions) and 43% for potential Policy Option 2 (some exemptions), as described in Section 4.3.2. **Table 6** below outlines the four scenarios considered for the reduction of $PM_{2.5}$ associated with residential wood burning emissions.

Table 6 Summary of Potential Policy Options on Ambient $PM_{2.5}$ Concentrations in Metro Vancouver

Scenario	Potential Policy Option	Percent Contribution of Wood Smoke to Ambient $PM_{2.5}$ Concentrations	Percent Compliance	Percent Decrease in Ambient $PM_{2.5}$ Concentrations During Wood Burning Season
A	1	15	53	7
B	2	15	43	5
C	1	35	53	16
D	2	35	43	13

In addition to the percent contribution and percent compliance assumptions summarized in **Table 6**, the following was also assumed in the prediction of health benefits associated with reductions in ambient $PM_{2.5}$ concentrations in Metro Vancouver:

- Forecast year for reduced $PM_{2.5}$ concentrations: 2017.
- Population growth: high-growth projection (based on a comparison of 2011 census data with AQBAT predictions for 2011 under medium growth [M4] or high-growth [H] projections).
- Baseline concentrations: generic baseline mean $PM_{2.5}$ concentration for this scenario [7.82 µg/m^3] was within the range of mean 24-hr ambient $PM_{2.5}$ concentrations measured at individual stations within Metro Vancouver during the burning season [4.22 to 8.09 µg/m^3] over 2 wood burning seasons (October 2013 to March 2014 and October 2014 to March 2015[7]).
- Reductions in $PM_{2.5}$ concentrations were limited to the upper end of the concentration distribution (i.e., 60th percentile and above) to preserve the ambient $PM_{2.5}$ concentrations resulting from other emission sources within the region (e.g., agricultural, industrial, chemical and mobile sources).

While implementation of a wood burning policy will generally only result in a reduction in $PM_{2.5}$ levels during cooler months, the effect on chronic health endpoints were also considered because residential wood burning emissions occur for at least a 6-month period (i.e., from October to March) year after year, and this type of exposure is expected to result in chronic health effects, even if they do not occur year round.

[7] The ambient $PM_{2.5}$ air concentration data was provided by Metro Vancouver. This data was used to identify which baseline concentration distribution to select. Based on statistical analysis, the generic distribution described the Metro Vancouver data better and was used for the AQBAT modelling.

5.3 AQBAT Model Results

5.3.1 Health Indicators

Health benefits due to reduced $PM_{2.5}$ levels in ambient air were measured as a reduction in the number of incidents of health endpoints associated with exposure to $PM_{2.5}$. The annual health benefits predicted under Scenarios A and B are summarized in **Table 7**. Both scenarios assume a residential wood burning contribution of 15 percent to ambient $PM_{2.5}$ concentrations. The decrease in $PM_{2.5}$ concentrations under either policy option will have a measurable effect on reducing the frequency of occurrence of health endpoints, with potential Policy Option 1 (Scenario A) having a measurably greater impact, as illustrated in the last column.

The annual health benefits predicted under Scenarios C or D were even more pronounced as these scenarios assumed a residential wood burning contribution of 35 percent, as summarized in **Table 8**. This is a direct result of a greater potential reduction in ambient $PM_{2.5}$ concentrations in regions where there is a higher contribution of residential wood burning to ambient $PM_{2.5}$ concentrations. Again the effect of potential Policy Option 1 (Scenario C) is measurably greater when compared with potential Policy Option 2 (Scenario D).

Table 7 Predicted Health Benefits with a Residential Wood Burning Contribution of 15 Percent (Scenarios A and B)

Health Endpoint	Reduction in Number of Incidents Under Potential Policy Option 1 (Scenario A)	Reduction in Number of Incidents Under Potential Policy Option 2 (Scenario B)	Net Benefit of Policy Option 1 over Policy Option 2
Acute Respiratory Symptom Days (non-asthmatics, all ages)	159,503	113,932	45,571
Adult Chronic Bronchitis Cases (≥25 years)	60	43	17
Asthma Symptom Days (all ages)	2877	2056	822
Cardiac ER Visits (all ages)	9	6	3
Cardiac HA (all ages)	7	5	2
Child Acute Bronchitis Episodes (<20 years)	371	265	105
Respiratory ER Visits (all ages)	24	17	7
Respiratory HA (all ages)	5	3	1
Restricted Activity Days (non-asthmatics, all ages)	6,6911	47,805	19,105
Chronic Exposure Respiratory Mortality (>30 years)	4	3	1
Chronic Exposure CV Mortality (>30 years)	7	5	2
Chronic Exposure IHD Mortality (>30 years)	35	25	10
Chronic Exposure Lung Cancer Mortality (>30 years)	8	6	2
Chronic Exposure Mortality (Respiratory, CV, IHD and Lung Cancer) (>30 years)	54	38	15
Cardiac + Respiratory HA	12	8	3
Cardiac + Respiratory ER Visits	33	23	9

CV – cerebrovascular
ER – emergency room
HA – hospital admission
IHD – ischemic heart disease

Table 8 Predicted Health Benefits with a Residential Wood Burning Contribution of 35 Percent (Scenarios C and D)

Health Endpoint	Reduction in Number of Incidents Under Potential Policy 1 (Scenario C)	Reduction in Number of Incidents Under Potential Policy 2 (Scenario D)	Net Benefit of Policy 1 over Policy 2
Acute Respiratory Symptom Days (non-asthmatics, all ages)	352,662	289,067	63,595
Adult Chronic Bronchitis Cases (≥25 years)	132	109	24
Asthma Symptom Days (all ages)	6,360	5,214	1,146
Cardiac ER Visits (all ages)	20	16	4
Cardiac HA (all ages)	15	12	3
Child Acute Bronchitis Episodes (<20 years)	813	668	145
Respiratory ER Visits (all ages)	53	43	9
Respiratory HA (all ages)	10	9	2
Restricted Activity Days (non-asthmatics, all ages)	147,767	121,175	26,593
Chronic Exposure Respiratory Mortality (>30 years)	9	7	2
Chronic Exposure CV Mortality (>30 years)	15	12	3
Chronic Exposure IHD Mortality (>30 years)	76	63	14
Chronic Exposure Lung Cancer Mortality (>30 years)	18	14	3
Chronic Exposure Mortality (Respiratory, CV, IHD and Lung Cancer) (>30 years)	118	97	21
Cardiac + Respiratory HA	25	21	5
Cardiac + Respiratory ER Visits	72	59	13

CV – cerebrovascular
ER – emergency room
HA – hospital admission
IHD – ischemic heart disease

5.3.2 Health-Related Economic Cost Savings

The cost savings associated with the reduction of health incidents outlined in **Table 7** (Scenario A and B) and **Table 8** (Scenario C and D) are provided below in **Table 9** and **10**, respectively. The difference in cost savings between potential Policy Option 1 and Option 2 is provided in the last column for comparison.

The greatest cost savings were associated with the health benefits predicted under Scenario C (i.e., $868,921,000) (**Table 10**). The costs associated with an exemption for lower income households to continue to use non-certified wood burning devices ranged from $112,378,000 (**Table 9**) to $155,582,000 (**Table 10**), depending on the assumed contribution of residential wood burning to ambient $PM_{2.5}$ levels.

Table 9 Cost Savings Associated with a Residential Wood Burning Contribution of 15 Percent

Health Endpoint	Cost Savings Under Potential Policy Option 1 (Scenario A)	Cost Savings Under Potential Policy Option 2 (Scenario B)	Net Benefit of Option 1 over Option 2
Acute Respiratory Symptom Days (non-asthmatics, all ages)	$1,645,000	$1,167,000	$478,000
Adult Chronic Bronchitis Cases (≥25 years)	$23,752,000	$16,935,000	$6,816,000
Asthma Symptom Days (all ages)	$192,000	$137,000	$55,000
Cardiac ER Visits/HA (all ages)	$51,000	$36,000	$15,000
Child Acute Bronchitis Episodes (<20 years)	$149,000	$107,000	$43,000
Respiratory ER Visits/HA (all ages)	$61,000	$44,000	$18,000
Restricted Activity Days (non-asthmatics, all ages)	$4,141,000	$2,961,000	$1,180,000
Chronic Exposure Respiratory Mortality (>30 years)	$28,121,000	$20,091,000	$8,030,000
Chronic Exposure CV Mortality (>30 years)	$45,599,000	$32,578,000	$13,022,000
Chronic Exposure IHD Mortality (>30 years)	$236,924,000	$169,870,000	$67,054,000
Chronic Exposure Lung Cancer Mortality (>30 years)	$54,436,000	$38,768,000	$15,668,000
Chronic Exposure Mortality (Respiratory, CV, IHD and Lung Cancer) (>30 years)	$365,080,000	$261,306,000	$103,774,000
Cardiac + Respiratory ER Visits/HA	$112,000	$80,000	$32,000
All endpoints	$395,072,000	$282,694,000	$112,378,000
Excluding Chronic Exposure Mortality	$29,992,000	$21,388,000	$8,604,000

CV – cerebrovascular
ER – emergency room
HA – hospital admission
IHD – ischemic heart disease

Table 10 Cost Savings Associated with a Residential Wood Burning Contribution of 35 Percent

Health Endpoint	Cost Savings Under Potential Policy Option 1 (Scenario C)	Cost Savings Under Potential Policy Option 2 (Scenario D)	Net Benefit of Potential Policy Option 1 over Option 2
Acute Respiratory Symptom Days (non-asthmatics, all ages)	$3,634,000	$2,999,000	$636,000
Adult Chronic Bronchitis Cases (≥25 years)	$52,250,000	$42,824,000	$9,427,000
Asthma Symptom Days (all ages)	$422,000	$348,000	$74,000
Cardiac ER Visits/HA (all ages)	$112,000	$92,000	$20,000
Child Acute Bronchitis Episodes (<20 years)	$326,000	$268,000	$58,000
Respiratory ER Visits/HA (all ages)	$136,000	$111,000	$24,000
Restricted Activity Days (non-asthmatics, all ages)	$9,152,000	$7,508,000	$1,644,000
Chronic Exposure Respiratory Mortality (>30 years)	$62,052,000	$50,888,000	$11,165,000
Chronic Exposure CV Mortality (>30 years)	$100,628,000	$82,572,000	$18,056,000
Chronic Exposure IHD Mortality (>30 years)	$520,612,000	$427,603,000	$93,010,000
Chronic Exposure Lung Cancer Mortality (>30 years)	$119,595,000	$98,128,000	$21,467,000
Chronic Exposure Mortality (Respiratory, CV, IHD and Lung Cancer) (>30 years)	$802,888,000	$659,190,000	$143,698,000
Cardiac + Respiratory ER Visits/HA	$248,000	$203,000	$45,000
All endpoints	$868,921,000	$713,340,000	$155,582,000
Excluding Chronic Exposure Mortality	$66,033,000	$54,150,000	$11,884,000

CV – cerebrovascular
ER – emergency room
HA – hospital admission
IHD – ischemic heart disease

5.4 HEATING AFFORDABILITY AND EQUITY EFFECTS

There are important links between fuel costs and health, across a number of important domains. The first of these are health effects associated with being unable to heat one's house to an adequate level. As described by the Marmot Review Team, low indoor temperatures have been associated with increased respiratory problems as well as increases in circulatory and coronary issues, with some evidence suggesting that lower temperatures show a stronger relationship to mortality from cardiovascular disease than mortality from respiratory disease (Marmot Review Team 2011).

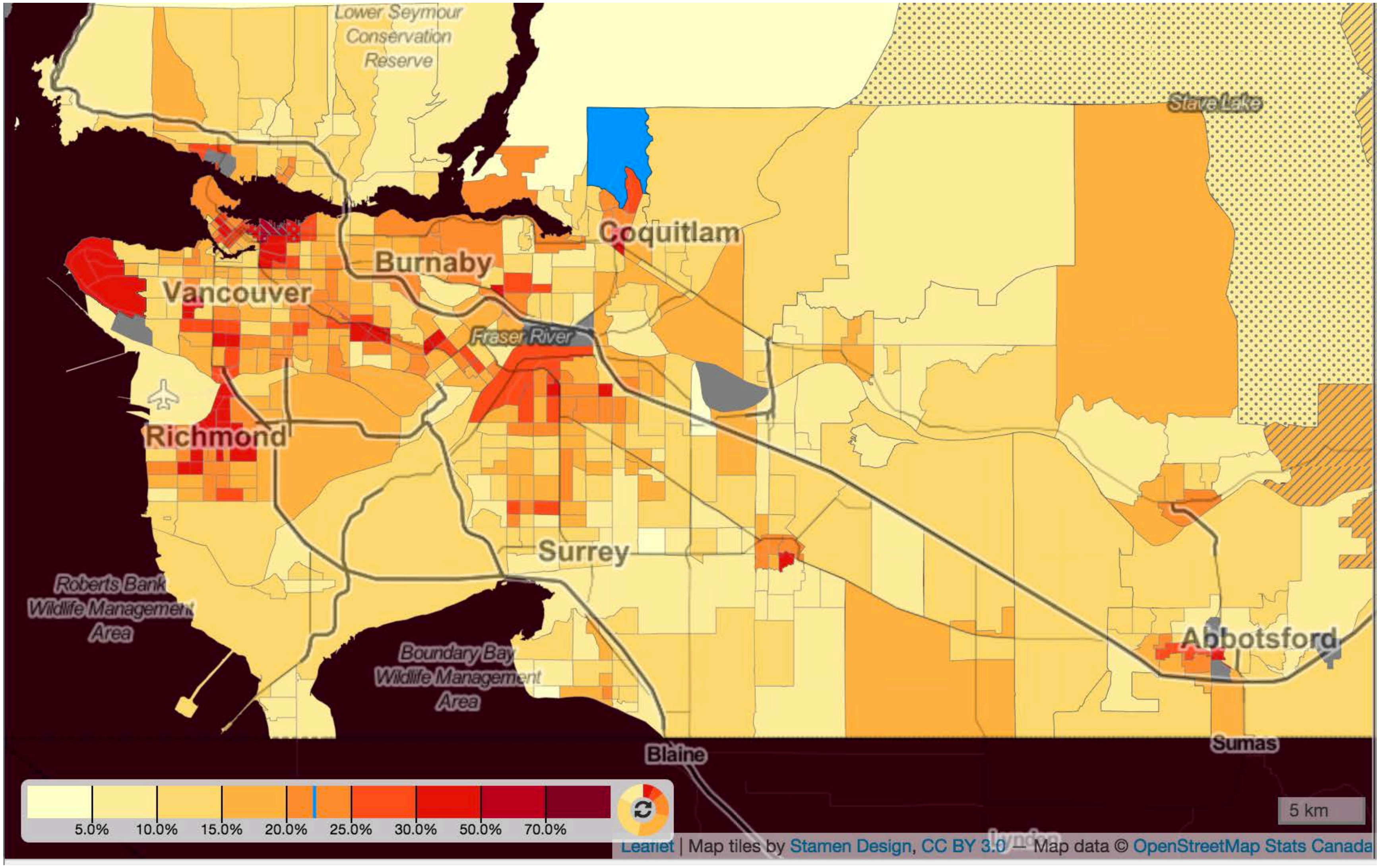
A second set of effects is linked to fuel poverty. Fuel poverty occurs when a family spends 10% or more of its income to achieve adequate warmth. Among low income families, high heating costs have been linked with food insecurity (the inability to access required amounts of safe, nutritional, and culturally acceptable foods) and housing insecurity, as families are forced to trade off among how to afford the basic necessities (Canterbury District Health Board 2014; Marmot Review Team 2011). No studies regarding the impact to low income households due to further reductions in income due to illness attributed or aggravated by exposure to wood smoke were found. However, such a “vicious circle’ effect is possible.

Finally, the added stress of affording heating costs and the effects from living in a cold home cause stress and affect mental wellbeing (Marmot Review Team 2011).

While the AQBAT model shows the costs that may be saved societally from a reduction in wood smoke exposure, it is important to bear in mind that individual families may not realize these benefits, and instead rely on wood burning stoves as an important family economic resource.

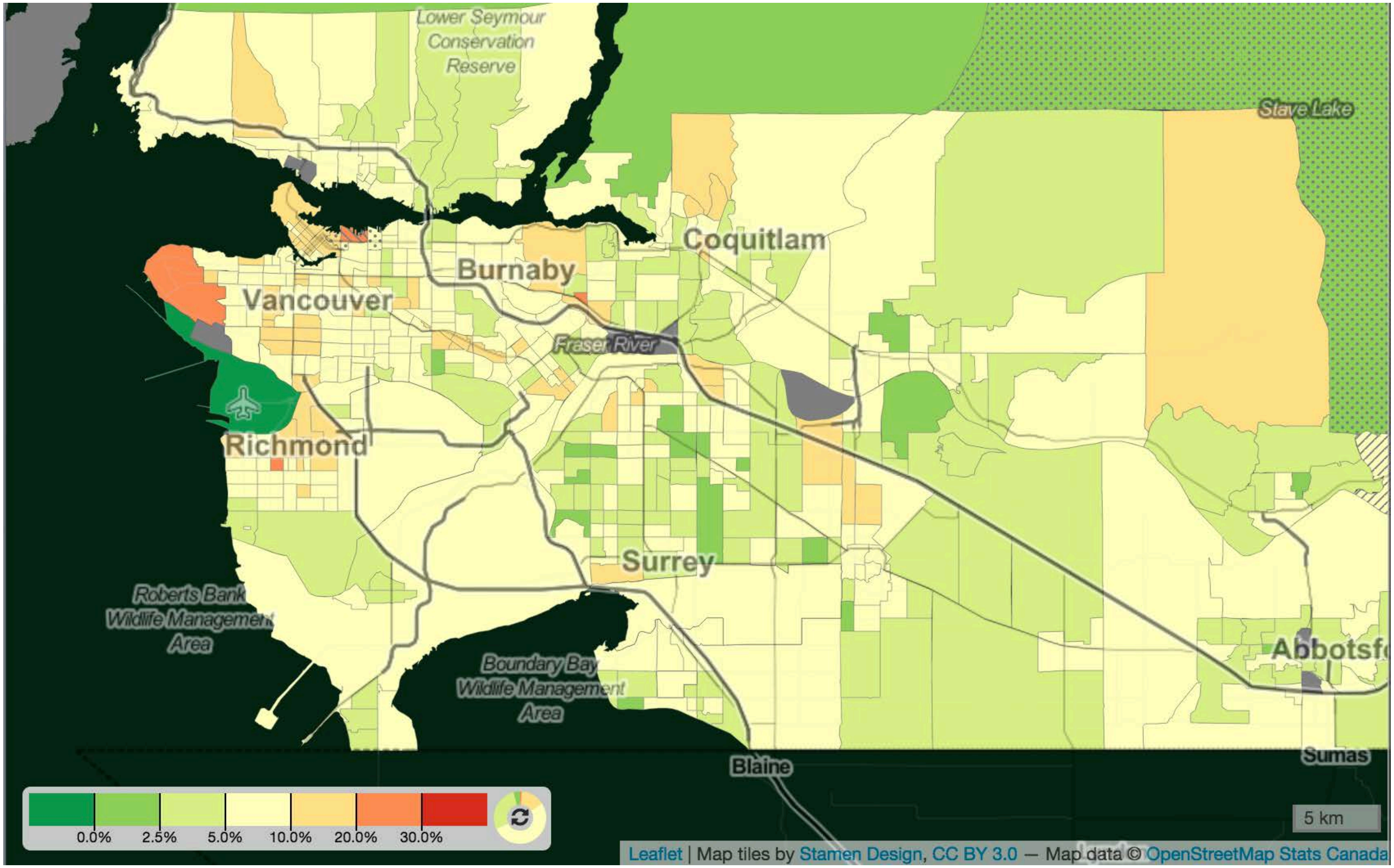
As described in Section 2, the *My Health My Community Survey* estimated that 31.7 percent of households across the Metro Vancouver area could be classified as low-income, with a household income of $40,000 or less. This figure is supported by data from Statistics Canada’s National Household Profile, which estimated the figure for the Vancouver census metropolitan area at around 31.4 percent (Statistics Canada 2013b). We do not know how many people in Metro Vancouver who are low income and rely on wood heating; it may be higher or lower than the average of 31% presented in Section 3. As described in Section 4.3.2, this analysis uses the assumption that the use of wood heating is the same in the low income population as in the population as a whole, resulting in an estimate of approximately 10% of the Metro Vancouver population who are both low income and using wood burning fireplaces (31% of 31.7% = ~10%). This equates to approximately 242,662 individuals or 87,349 households. This represents the population that is particularly vulnerable to adverse effects associated with increased heating costs. As described above, if additional money needs to be devoted to energy costs, then less will be available among these families for food, shelter and other basic necessities.

Figures 7 and **8** present two different ways of looking at the distribution across Metro Vancouver of those who may be more likely to experience fuel poverty. **Figure 7** shows the prevalence of household poverty as of 2010, based on the after-tax low income threshold used by Statistics Canada. **Figure 8** shows those areas where shelter costs are higher than incomes. Although critiques have been leveled at the methodology, these two maps give an approximate idea of where people who may be hardest hit by a reduction in wood burning options may be found.



Source: https://censusmapper.ca/maps/119#10/49.3063/-122.8622

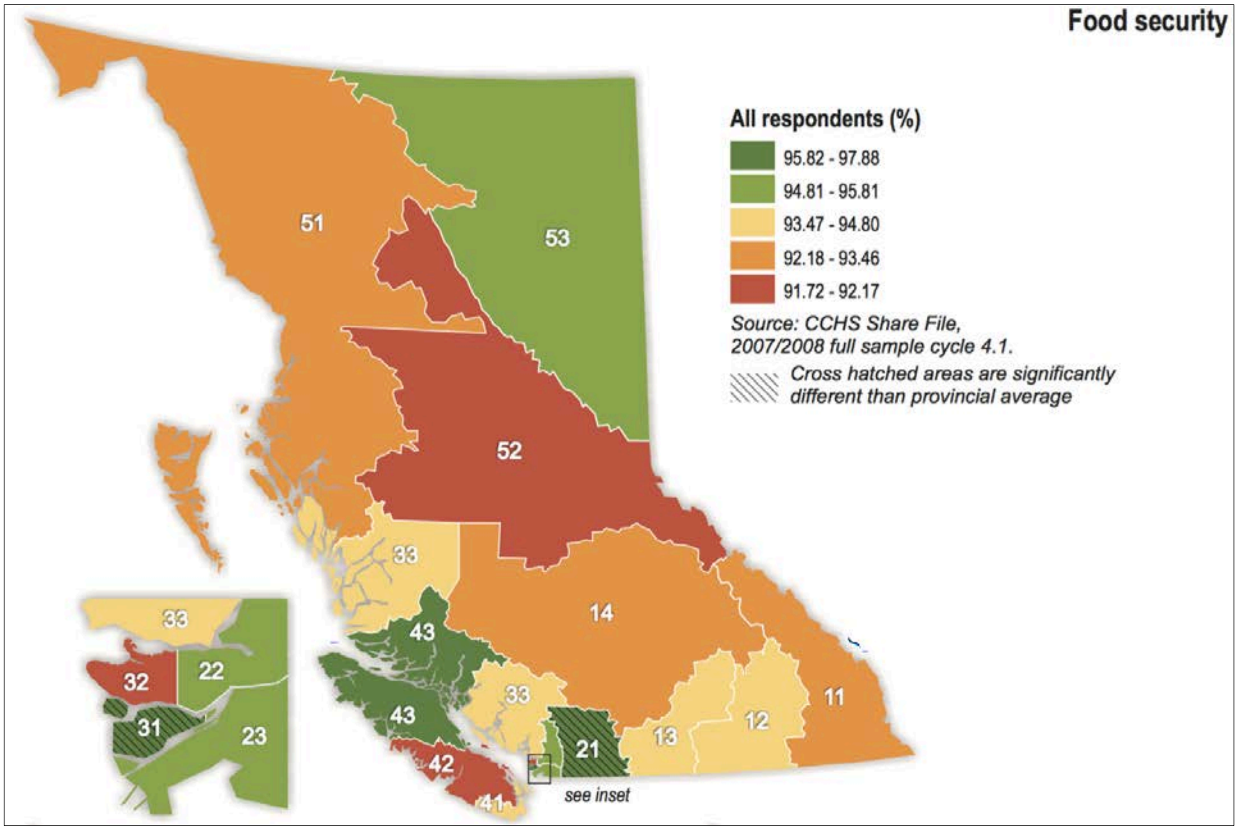
Figure 7 Prevalence of Poverty Based on After-Tax Low-Income Threshold



Source: https://censusmapper.ca/maps/36#11/49.2490/-123.1475

Figure 8 Prevalence of Households with Shelter Costs Higher than Income

Figure 9 shows the prevalence of food insecurity across BC and the Metro Vancouver region, at a slightly less-fine grain of detail. While the vast majority of the population is food secure, between 5 and 8 percent of the population is food insecure, which may be exacerbated by increased heating costs or the cost of replacing current heating sources.



Source: British Columbia Atlas of Wellness, 2nd Edition. http://www.geog.uvic.ca/wellness/wellness2011/

Figure 9 Food Security Across British Columbia

From an equity perspective, potential Policy Option 2 allows exemptions for low-income households where conventional wood heating devices are the primary source of heat.

6.0 LIMITATIONS AND UNCERTAINTY

The benefits associated with the two proposed policy options is difficult to accurately determine since the quantification required integration of multiple variables (and associated uncertainty), including baseline ambient air quality, the impact of residential wood burning on ambient air quality, and human behaviour (compliance), among others. Key study limitations and uncertainties are provided in **Table 11**.

Table 11 Study Limitations and Uncertainty

Uncertainty/Limitation	Comments
Residential wood smoke contribution to ambient $PM_{2.5}$ concentrations	Ambient $PM_{2.5}$ concentrations were estimated based on emission inventory and ambient monitoring data provided by Metro Vancouver. Although there will be some sub-regional differences, the data is reliable and adequately describe region-wide $PM_{2.5}$ levels.
Participation/compliance rate	$PM_{2.5}$ emission reductions depend on participation and compliance rates. The value selected under Policy Option 1 (45%) encompass a reasonable compliance rates (>50%) that are possible (Databuild Research & Solutions, 2016). A reduction for Policy Option 2 (35%) is a reasonable estimate of the number of low income households that would be excluded under this option. If actual rates are lower/higher, then expected benefits will be lower/higher than estimated.
Sub-regional differences	There are regional differences that will influence the benefits that may be realized in each sub-region. Areas with high/low wood burning appliance use may experience more/less benefits than predicted. Overall, the results are considered representative.
AQBAT – health benefits	Health effects are based on current estimates of the dose-response (CRFs) of $PM_{2.5}$ exposures at the concentrations evaluated. The CRFs have been approved by Health Canada.
AQBAT - economic valuation	The cost savings are based on Canada- wide estimates in 2010 dollars. Actual costs for Metro Vancouver and current may differ from those estimated. The economic valuation method and assumptions have been approved by Health Canada.
AQBAT – chronic exposure mortality	Chronic exposure mortality was calculated even though $PM_{2.5}$ reductions will be realized only during the wood burning season. Furthermore, the economic valuation model used to estimate mortality costs are based on willingness-to-pay estimates. Compared with other endpoints, benefits due to reduced mortality account for 92 percent of the total cost savings. Including mortality costs overshadow benefits gained from other reduce health effects that have more importance on a day to day basis. This is expected to be especially true for low income families.
AQBAT – $PM_{2.5}$ composition	The CRFs for $PM_{2.5}$ in AQBAT are based on epidemiological studies conducted in urban areas. The $PM_{2.5}$ in wood smoke will vary somewhat from the composition typically found in urban air. Subtle differences in $PM_{2.5}$ composition are not expected to significantly alter the study results.
Other pollutants	Other pollutants present in wood smoke including NOx, VOCs and PAHs were not considered. Some of these substances are known to cause various adverse health effects, including cancer. There are health benefits associated with reduced exposure to these substances that have not been considered (quantified). Therefore, actual health benefits may be higher than estimated

Uncertainty/Limitation	Comments
Other [*socio-economic*] effect indicators	There are benefits associated with residential wood burning that could not be quantified. For example, low income families reliant on wood burning may have less disposable income to spend on food and other necessities if they are required to switch to high efficiency appliances or natural gas (if available). For many families, continued wood burning may be much more important for health and wellness than any benefit gained from residential wood smoke emission reductions.
Indoor air quality	This study did not consider potential health benefits associated with improvements to indoor air quality. These benefits may be significant based on the findings of a study that found that $PM_{2.5}$ concentrations in indoor air were reduced by more than 70% following replacement of non-certified to certified wood burning appliances (Ward et al., 2008).

7.0 DISCUSSION AND RECOMMENDATIONS

Four scenarios representing two potential policy options were considered. Based on two different estimates of residential wood smoke contribution to ambient $PM_{2.5}$ concentrations and two different participation rates, the following decreases in ambient $PM_{2.5}$ concentrations due to reduced residential wood smoke emissions were evaluated:

Scenario	Description	Percent Decrease in Ambient $PM_{2.5}$ Concentrations During Wood Burning Season
A	Option 1 (no exemptions) and moderate contribution of wood smoke to ambient $PM_{2.5}$ concentrations	7
B	Option 2 (some exemptions) and moderate contribution of wood smoke to ambient $PM_{2.5}$ concentrations	5
C	Option 1 (no exemptions) and high contribution of wood smoke to ambient $PM_{2.5}$ concentrations	16
D	Option 2 (some exemptions) and high contribution of wood smoke to ambient $PM_{2.5}$ concentrations	13

The results of the AQBAT modelling assessment indicate that the annual cost savings associated with the predicted decreases in $PM_{2.5}$ concentrations in Metro Vancouver range from ~$282 million (some exemptions, moderate contribution of wood smoke to ambient $PM_{2.5}$ concentrations) to ~$869 million (no exemptions, high contribution of wood smoke to ambient $PM_{2.5}$ concentrations) when all health endpoints are considered. Further analysis of the results indicates that chronic exposure mortality accounts for 92% of total cost. The high cost of mortality is related to the economic valuation model (willingness-to-pay) used to estimate mortality costs, which in AQBAT is ~$6.5 million for each premature death avoided.

While chronic exposure mortality is relevant to the assessment, it is also important to understand the benefits associated with avoidance of acute health effects since these impact individual wellness on a daily basis. This analysis is helpful when considering the cost-benefit to lower income families, especially those reliant on residential wood burning for heat. Such an examination allows for a comparison of the health benefit gained due to reduced exposure to wood smoke with the potential for poorer health due to less money available to purchase food and other necessities because of the additional costs of switching to certified appliances or an alternate source of heating (e.g., electrical). Acute health effects other than mortality are also more relevant when considering potential savings to the health care system as it is more reflective of “out of pocket” costs. Excluding chronic exposure mortality, the annual cost savings range from ~$21 million (some exemptions, moderate contribution of wood smoke to ambient $PM_{2.5}$ concentrations) to ~$66 million (no exemptions, high contribution of wood smoke to ambient $PM_{2.5}$ concentrations) for the Metro Vancouver area.

For the purposes of evaluating the two policy options, the net benefits are estimated to range from a low of ~$21 million (some exemptions, moderate contribution of wood smoke to ambient $PM_{2.5}$ concentrations, excluding chronic exposure mortality) to a high of ~$869 million (no exemptions, high contribution of wood smoke to ambient $PM_{2.5}$ concentrations, including mortality).

Examination of the differences in cost savings between the two policies show that the acute health-related cost savings are approximately $10 million if no exemptions are allowed. However, Option 1 requires costs to be incurred for alternative heating, which may disproportionately affect low income households. Input from health authorities and local experts indicated that equity effects should be considered.

A reduction of cardiorespiratory events would have the greatest benefit among those groups who have the highest susceptibility to adverse effects from cardiorespiratory challenges: the elderly, the very young, and those with pre-existing conditions. A reduction in emissions may have a noticeable impact on personal health experience and subsequent quality of life among these groups.

Those who are most at risk of experiencing hardship as a result of the policy comprise a different group: low-income households for whom increased monthly heating costs or a capital expenditure on an upgraded stove may result in a reduced ability to purchase food, shelter or other basic necessities.

Both these groups number in the tens or hundreds of thousands across the Metro Vancouver region (and many people may be members of both groups).

Regardless of the option implemented, it is emphasized that successful implementation of any residential wood smoke reduction programs requires public education outreach programs presenting the association between residential wood smoke emissions, ambient air quality and health. Based on the study results and lessons learned from other jurisdictions as well as input from local experts, significant benefits from regulatory measures to reduce residential wood smoke emissions can be realized. However, there can be adverse effects on the wellness of low income families and others heavily reliant on wood for heating.

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APPENDIX A

Summary of Literature Search and Jurisdictional Review

A review of recent literature was conducted to provide information on the toxicity and health effects associated with wood smoke exposure. Two databases were the focus of the literature review (Web of Science and PubMed), using the search terms "wood smoke" and "epidemiology". Over 250 search results were retrieved (63 for Web of Science, 224 for PubMed). For both literature searches, results were evaluated and included if they contained (a) health effects that are linked to wood smoke exposure; (b) the study was based in Canada, United States, Europe, Australia, New Zealand; (c) provided air quality data linked to exposure and health effects associated with wood burning (wildfire reports were excluded).

The results of the literature review can be categorized in terms of health impacts. Many of the selected studies had health impact effects that are evaluated as part of the Air Quality Benefits Assessment Tool (AQBAT). These effects can be quantitatively assessed and economically valued. Acute exposure mortality (Robinson *et al.,* 2007; Madsen, 2012) and chronic exposure mortality (Health Canada, 2013; Johnston *et al.,* 2013; Lepeule *et al.,* 2012; Robinson 2005; Pope *et al.,* 2002; Robinson *et al.,* 2007; Galea *et al.,* 2013; Madsen 2012; Bell *et al.,* 2013; Hallowell 2015; Washington State Department of Ecology, 2009; Hales *et al.,* 2000; Gan *et al.,* 2013) are premature deaths associated with pollutant exposure but not associated with respiratory or cardiac illness. Mortalities due to cardiovascular disease, respiratory diseases, cerebrovascular effects (such as stroke) and ischemic heart disease have been linked to chronic exposure to air pollution (Health Canada, 2013; Robinson *et al.,* 2007; Hallowell 2015; Hales *et al.,* 2000). Additionally, so too has mortality from lung cancer (Lepeule *et al.,* 2012; Pope *et al.,* 2002; Robinson *et al.,* 2007). Respiratory symptoms including wheezing, decreased air flow, respiratory tract infection, and others symptoms, are unsurprisingly associated with exposure to air pollution, and wood smoke in particular (Noonan *et al.,* 2012; Kajdasz *et al.,* 2001; Zelikoff *et al.,* 2002; Guggisberg *et al.,* 2003; Sood *et al.,* 2010; Bennett *et al.,* 2010; Golpe *et al.,* 2014; Naehar *et al.,* 2005, 2007; Laubach and Kipen, 2011; Kajbafzadeh *et al.,* 2015). Asthma is categorized in AQBAT separate from the other respiratory symptoms, and is strongly linked to exposure to particulate matter sized 2.5 microns or smaller ($PM_{2.5}$), which is a primary component of wood smoke (Barry *et al.,* 2010; van Miert *et al.,* 2011; Salam *et al.,* 2004; Washington State Department of Ecology, 2009; Boman *et al.,* 2003; Koenig *et al.,* 1993; Yu *et al.,* 2000; Health Canada, 2013). Acute bronchitis episodes in children (Epton *et al.,* 2008; Ware *et al.,* 2014; Torres-Duque *et al.,* 2008; Smith *et al.,* 2004; Browning *et al.,* 1990) and adult chronic bronchitis (Galea *et al.,* 2013) are linked to air pollution, similar to the other respiratory symptoms, but are categorized separately in AQBAT. Cardiac emergency room visits and hospital admissions (Mc Gowan *et al.,* 2002; Schreuder *et al.,* 2006; Galea *et al.,* 2013; Hallowell *et al.,* 2015; Washington State Department of Ecology, 2009; Health Canada, 2013), as well as respiratory emergency room visits and hospital admissions (Mc Gowan *et al.,* 2002; Schreuder *et al.,* 2006; Ostro *et al.,* 2009; Galea *et al.,* 2013; Hallowell *et al.,* 2015; Karr *et al.,* 2009; Washington State Department of Ecology, 2009; Boman *et al.,* 2003; Gan *et al.,* 2013; Sheppard *et al.,* 1999; Health Canada, 2013) are quantified, as they are closely linked to exposure to air pollution, including wood smoke-sourced $PM_{2.5}$. Aside from very specific diagnosis of cardiovascular and respiratory symptoms, more general categories such as activity restriction days due to air pollution are also considered linked to wood smoke air pollution (Galea *et al.,* 2013).

Other health impacts not quantified in AQBAT have also been associated with exposure to air pollution, and wood smoke in particular. Otitus media (infection of the inner ear) has been linked to wood smoke (Naehar *et al.,* 2005, 2007) and to nitrogen oxide, $PM_{2.5}$ and wood smoke (MacIntyre *et al.,* 2011). The study conducted by McIntyre and colleagues evaluated various components of wood smoke (CO, NO, NO_2, O_3, $PM_{2.5}$, PM_{10}, SO_2) in the Georgia Basin Airshed (including Vancouver and Victoria), but found the strongest links to inner ear effect to be associated with NO, $PM_{2.5}$ and wood smoke. Ocular effects, including minor effects such as watery or itchy eyes (Guggisberg *et al.,* 2003) and major effects such as cataracts (Torres-Duque *et al.,* 2008) are linked to the duration and level of wood smoke exposure. Hospital admission for appendicitis are linked with PM_{10} exposure, the source of which is "solid fuel domestic heating" (McGowan *et al.,* 2002). Neurological impacts including dementia have been linked to $PM_{2.5}$ concentrations (Kioumourtzoglou *et al.,* 2016) and aldehydes in wood smoke (Zelikoff *et al.,* 2002). While not categorized in AQBAT, these health impacts reflect the plethora of potentially hazardous effects that may be associated with wood smoke exposure.

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Health Benefits of Decreased Wood Smoke Emissions											
Article title	**Article author**	**Year**	**Publication Type**	**Article quick summary**	**Location**	**Contaminant**	**Source**	**Exposure Level**	**Exposure Duration**	**Health Impact Category**	**Health Effect**
Evaluation of interventions to reduce air pollution from biomass smoke on mortality in Launceston, Australia: retrospective analysis of daily mortality, 1994-2007	Johnston et al.	2013	Primary Research - Interventional	Comparison study of health impacts from wood smoke between two Australian cities, one with exchange program (Launceston) and one without (Hobart)	Australia	PM_{10}	Assumed to be wood heaters	Decrease from 23.7 to 18.4 $\mu g/m^3$	**Chronic:** Study duration 1997-2000 (pre-) and 2001-2007 (post-)	Mortality - All	Percent decrease of 13.4% (Launceston data only)
										Mortality - Cardiovascular	Percent decrease of 29.5% (Launceston data only)
										Mortality - Respiratory	Percent decrease of 24.6 % (Launceston data only)
Experimental Exposure to Wood-Smoke Particles in Healthy Humans: Effects on Markers of Inflammation, Coagulation, and Lipid Peroxidation	Barregard et al.	2006		Experimental evaluation of exposing human subjects to wood smoke							
A rural community intervention targeting biomass combustion sources: effects on air quality and reporting of children's respiratory outcomes	Noonan et al	2012	Primary Research - Interventional	Evaluation of health impacts of wood stove replacement program	United States (Libby, Montana)	$PM_{2.5}$	Wood stoves	Decrease of 5 $\mu g/m^3$	**Chronic:** metrological data from 2003 - 2009 and health survey data from 2006 - 2009	Respiratory	Children - wheezing - 26.7% reduced odds
											Children - itchy/watery eyes - 33.2% reduced odds
											Children - sore throat - 31.6% reduced odds
											Children - cold infection - 25.4 % reduced odds
											Children - bronchitis - 54.6 % reduced odds
											Children - influenza - 52.3 % reduced odds
											Children - throat infection - 45.1% reduced odds
Health Effects of Increases in Wood Smoke Emissions (less than 10$\mu g/m^3$)											
Article title	**Article author**	**Year**	**Publication Type**	**Article quick summary**	**Location**	**Contaminant**	**Source**	**Exposure Level**	**Exposure Duration**	**Health Impact Category**	**Health Effect**
Experimental Exposure to Wood-Smoke Particles in Healthy Humans: Effects on Markers of Inflammation, Coagulation, and Lipid Peroxidation	Barregard et al.	2006		Experimental evaluation of exposing human subjects to wood smoke							
Ambient woodsmoke and associated respiratory emergency department visits in Spokane, Washington	Schreuder et al	2013	Primary Research - Observational	Vegetative burning more strongly associated with respiratory effects than other sources (including wood smoke)	Spokane Washington	$PM_{2.5}$	Wood combustion	Increase of 10.1 $\mu g/m^3$	**Chronic:** air quality data from 1995 - 2002	Cardiovascular	Relative risk of hospital visit between 0.995 - 1.015
										Respiratory	Relative risk of hospital visit between 1.009 - 1.018
Using $PM_{2.5}$ concentrations to estimate the health burden from solid fuel consumption,, with application to Irish and Scottish homes	Galea et al	2013	Primary Research - Observational	Study estimates the potential population health burden from exposure to combustion-derived particulate air pollution in domestic settings in Ireland and Scotland	Ireland and Scotland	$PM_{2.5}$	Wood smoke	Estimated 2.11 $\mu g/m^3$ over baseline	**Chronic:** tens of years	Mortality	Additional annual cases of all-cause mortality - 21
										Respiratory	Additional annual cases of chronic bronchitis - 55
										Respiratory	Annual lower respiratory tract symptom days (including cough) - 30,100
										Respiratory	Annual restricted activity days - 38,000
										Cardiovascular	Additional annual cases of cardiovascular hospital visits - 4
										Respiratory	Additional annual cases of respiratory hospital visits - 9
The short-term effect of 24-h average and peak air pollution on mortality in Oslo, Norway	Madsen	2012	Primary Research - Observational		Norway	$PM_{2.5}$	Exhaust and Wood burning	Increase of 10 $\mu g/m^3$	**Acute:** 24 hour	Mortality	Increase in death 0-5 days lag - 2.8%
Adverse health effects from ambient air pollution in relation to residential wood combustion in modern society	Boman, Forsberg and Jarvholm	2003	Review	Review of 9 published articles about health impacts of wood smoke	Port Alberni BC	PM_{10}	Ambient wood smoke	Increase of 10 $\mu g/m^3$	**Chronic:** 1 year	Respiratory	Reduction of peak expiratory flow of 0.55 L/min (Vedal et al., 1998)
						PM_{10}		Increase of 10 $\mu g/m^3$		Respiratory	increased odds of cough - relative risk of 1.08 (Vedal et al., 1998)
					Christchurch, New Zealand	Nitrogen dioxide	Ambient wood smoke	Increase of 10 $\mu g/m^3$		Respiratory	Relative risk of increased inhaler use - 1.42 (Harre et al, 1997)
						Nitrogen dioxide		Increase of 10 $\mu g/m^3$		Respiratory	Relative risk of increased nebulizer use - 2.81 (Harre at al., 1997)
Associations of ambient air pollution with Chronic Obstructive Pulmonary Disease Hospitalization and Mortality	Gan et al.,	2013	Primary Research - Observational	Long-term exposure to elevated woodsmoke pollution was associated with an increased risk of COPD hospitalization	Vancouver	Not specified	Woodsmoke	"high tertile" (third)		Respiratory	Relative risk of hospitalization for chronic obstructive pulmonary disease - 1.17
						Not specified	Woodsmoke	"high tertile" (third)		Mortality	Relative risk of death - 0.78
Health Effects of Increases in Air Pollution Concentrations (less than 10 $\mu g/m^3$)											
Article title	**Article author**	**Year**	**Publication Type**	**Article quick summary**	**Location**	**Contaminant**	**Source**	**Exposure Level**	**Exposure Duration**	**Health Impact Category**	**Health Effect**
Chronic Exposure to Fine Particles and Mortality: An Extended Follow-up of the Harvard Six Cities Study from 1974 to 2009	Lepeule et al.	2012	Primary Research - Observational	Extension of epidemiological study of six cities evaluating link between lower levels of PM2.5 and health impacts	United States (Harvard Six Cities)	$PM_{2.5}$	Not specified	Increase of 10 $\mu g/m^3$	**Chronic:** $PM_{2.5}$ from 1974-2009 and health survey data from 1979 - 2009	Mortality	All-cause - 14% increased risk
										Cardiovascular	Death - 26% increased risk
										Respiratory	Lung cancer death - 37% increased risk
										Respiratory	COPD death - 17% increased risk
Lung Cancer, Cardiopulmonary mortality, and Long-term exposure to Fine Particulate Air Pollution	Pope et al	2002	Primary Research - Observational	Long-term exposure to combustion-related fine particulate air pollution is an important environmental risk factor for cardiopulmonary and lung cancer mortality.	United States	$PM_{2.5}$	Not specified	Increase of 10 $\mu g/m^3$	**Chronic:** data from multiple years	Mortality	All-cause - 4-6% increased risk
										Cardiovascular	Death - 6-9% increased risk
										Respiratory	Lung Cancer Death - 8-14% increased risk
The effects of fine particle components on respiratory hospital admissions in children	Ostro et al	2009	Primary Research - Observational	Components of Pm2.5 are associated with hospitalization for several childhood respiratory diseases including pneumonia, bronchitis, and asthma	California	NO_3 (nitrates)	not specified (includes exhaust, wood smoke, other	Increase of 5.7 $\mu g/m^3$	**Subchronic:** Between 227 and 381 days of air quality data	Respiratory	Excessive risk of hospital admission of 3.3%
						SO_4 (sulfates)		Increase of 1.5 $\mu g/m^3$		Respiratory	Excessive risk of hospital admission of 3.0%
Long-term $PM_{2.5}$ Exposure and neurological hospital admission in the Northeastern United States	Kioumourtzoglou et al	2016	Primary Research - Observational	examined the relationship between long term exposure to $PM_{2.5}$ and neurological diseases in humans	Northeastern US	$PM_{2.5}$	air pollution	annual increase of 1 $\mu g/m^3$	**Chronic:** lifelong	Neurological	Dementia hazard ratio of 1.08
											Alzheimer's hazard ratio of 1.15
											Parkinson's hazard ratio of 1.08
								annual increase of 5 $\mu g/m^3$	**Chronic:** lifelong	Neurological	Dementia hazard ratio of 1.46
											Alzheimer's hazard ratio of 2
											Parkinson's hazard ratio of 1.44
Evidence on Vulnerability and Susceptibility to Health Risks Associated with Short-term exposure to particulate matter: A systematic review and meta-analysis	Bell et al	2013	Review	Analyse variation between age, sex, race and their risk of PM associated hospitalization and death	Global	PM_{10}	air pollution	Increase of 10 $\mu g/m^3$	**Chronic**	Mortality	0.64% higher risk of death in populations $\geq$ 65
											0.34% higher risk of death in populations <64
											0.55% higher risk of death in women
											0.50% higher risk of death in men

Health Benefits of Decreased Wood Smoke Emissions											
Adverse health effects from ambient air pollution in relation to residential wood combustion in modern society	Boman, Forsberg and Jarvholm	2003	Review	Review of 9 published articles about health impacts of wood smoke	Washington	$PM_{2.5}$	air pollution	Increase of 9.5 μg/m^3			Relative risk for daily hospital admissions for asthma - 1.15 (Norris et al, 1999)
						Carbon monoxide		Increase of 0.6 ppm			Relative risk for daily hospital admissions for asthma - 1.10 (Norris et al, 1999)
Daily mortality in relation to weather and air pollution in Christchurch, New Zealand	Hales et al.,	2000	Primary Research - Observational	Evidence of health consequences of fuel combustion, both in the short term and in the long term	Christchurch, New Zealand	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic:** June 1988 to Dec 1993	mortality	Increase of all-cause mortality of 1%
										mortality	Increase of respiratory mortality of 4%
Associations of ambient air pollution with Chronic Obstructive Pulmonary Disease Hospitalization and Mortality	Gan et al.,	2013	Primary Research - Observational	Long-term exposure to elevated woodsmoke pollution was associated with an increased risk of COPD hospitalization	Vancouver	$PM_{2.5}$	Traffic-related air pollutants	Increase of 1.58 μg/m^3	**Chronic:** 5 year exposure, 4 year follow-up	Respiratory	Relative risk of hospitalization for chronic obstructive pulmonary disease - 1.15
						Nitrogen dioxide	Traffic-related air pollutants	Increase of 8.40 μg/m^3		Respiratory	Relative risk of hospitalization for chronic obstructive pulmonary disease - 1.17
						$PM_{2.5}$	Traffic-related air pollutants	Increase of 1.58 μg/m^3		Mortality	Relative risk of death - 1.17
						Nitrogen dioxide	Traffic-related air pollutants	Increase of 8.40 μg/m^3		Mortality	Relative risk of death - 1.24
Residential Air Pollution and otitis media during the first two years of life	MacIntyre et al.,	2011	Primary Research - Observational	Modest but consistent associations were found between some measures of air pollution and otitis media in a large birth cohort exposed to relatively low levels of ambient air pollution.	Southwestern BC (including Vancouver and Victoria)	Nitrogen dioxide	ambient air	Increase of 10 μg/m^3	**Chronic:** 2 years	Auditory	Relative risk of physician visits for otitis media (middle ear inflammation) - 1.10
						$PM_{2.5}$	ambient air	Increase of 1.8 μg/m^3			Relative risk of physician visits for otitis media (middle ear inflammation) - 0.89
						PM_{10}	ambient air	Increase of 2.8 μg/m^3			Relative risk of physician visits for otitis media (middle ear inflammation) - 1.06
						Sulfur dioxide	ambient air	Increase of 3.2 μg/m^3			Relative risk of physician visits for otitis media (middle ear inflammation) - 1.00
Effects of ambient air pollution on non-elderly asthma hospital admissions in Seattle, Washington, 1987 - 1994	Sheppard et al.,	1999	Primary Research - Observational	PM and carbon monoxide jointly associated with asthma admissions	Seattle	coarse PM	ambient air	Increase of 9.3 μg/m^3	**Subchronic:** April - October	Respiratory	Increase in rate of asthma hospital admissions - 4-5%
						PM_{10}	ambient air	Increase of 19 μg/m^3		Respiratory	Relative rates of asthma hospital admissions - 1.05
						$PM_{2.5}$	ambient air	Increase of 11.8 μg/m^3		Respiratory	Relative rates of asthma hospital admissions - 1.04
						coarse PM	ambient air	Increase of 9.3 μg/m^3		Respiratory	Relative rates of asthma hospital admissions - 1.04
Effects of ambient air pollution on symptoms of asthma in Seattle-Area children in the CAMP study	Yu et al.,	2000	Primary Research - Observational	Effects of PM and carbon monoxide on asthma symptoms	Seattle	Carbon monoxide	ambient air	Increase of 1 ppm	**Subchronic:** 58 days	Respiratory	Increase in asthma symptoms - 30%
						PM_1	ambient air	Increase of 10 μg/m^3		Respiratory	Increase in asthma symptoms - 18%
						PM_{10}	ambient air	Increase of 10 μg/m^3		Respiratory	Increase in asthma symptoms - 11%
Canadian Smog Science Assessment	Health Canada	2013	Review	Assess the effects of smog on human health	Los Angeles	concentrated ambient particles	experimentally generated	200 μg/m^3	**Acute**: 2 hours	Respiratory	no changes in lung function or respiratory symptoms during exercise observed (Gong et al., 2004, 2005)
					Toronto	concentrated ambient particles	experimentally generated	150 μg/m^3 as $PM_{2.5}$ and ozone 120 ppb	**Acute:** 2 hours	Cardiovascular	significant brachial artery vasoconstriction (Brook et al., 2002)
					Global	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	All-cause mortality increased 0.63% (Stieb et al., 2002)
					Canada	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Total mortality increased 0.47% (Burnett et al., 2004)
					Canada	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Total non-accidental mortality increased 0.60% (Burnett et al., 2004)
					Canada	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in daily mortality from diabetes 8.82% (Goldberg et al., 2006)
					Canada	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in daily non-accident mortality 3.89% (Goldberg et al., 2006)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.22% (Dominici et al., 2003)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.12% (Roberts and Martin, 2006)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.24% (Zeka and Schwartz, 2004)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in all-season mortality of 0.19% (Peng et al., 2005)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.2% (Welty and Zeger, 2005)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.36% (Schwartz 2004)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.45% (cumulative 3-day lag) (Zeka et al., 2005)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.42% (Zeka et al., 2006)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.25% (<65 years old) (Zeka et al., 2006)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.25% (>75 years old) (Zeka et al., 2006)
					United States	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 1.21% (Franklin et al., 2007)
					United States	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 5.52% (≥ 65 years old) (Klemm et al., 2004)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 1.14% (Klemm et al., 2004)
					United States	PM_{10}	ambient air	34 μg/m^3 hourly increase (10 μg/m^3 daily)	**Chronic**	Mortality	Increase in daily mortality of 2.06% (Staniswalis et al., 2005)
					Europe	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.71%, all subjects (Aga et al., 2003)
					Europe	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.79%, >65 years old (Aga et al., 2003)
					Europe	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 0.71% (Touloumi et al., 2004)
					Europe	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in mortality of 1.61% (40 day lag) (Zanobetti et al., 2002)
					Canada	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Respiratory mortality excess risk was 1.32% (Steib et al., 2003)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in cardiovascular/respiratory mortality of 0.31% (Dominici et al., 2003)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Mortality	Increase in cardiovascular/respiratory mortality of 0.17% (Roberts and Martin, 2006)

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Canadian Smog Science Assessment	Health Canada	2013	Review	Assess the effects of smog on human health	United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Mortality	Increase in respiratory mortality of 0.87% (3-d cumulative) (Zeka et al, 2005)
					Europe	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Increase in respiratory mortality of 0.71% (Analitis et al, 2006)
					Europe	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Increase in respiratory mortality of 1.9% (Eilstein et al., 2004)
					Europe	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Increase in respiratory mortality of 1.74% (Biggeri et al., 2005)
					Netherlands	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Increase in pneumonia mortality (45 - 64 age group) of 6.95% (Fischer et al., 2003)
					Netherlands	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Increase in pneumonia mortality (≥ 75 age group) of 2.94% (Fischer et al., 2003)
					Finland	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Increase in respiratory mortality of 2.13% (Penttinen et al, 2004)
					Canada	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality excess risk was 0.3% (Steib et al., 2003)
					Canada	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Cardiovascular mortality excess risk was 3.28% (Villeneuve et al., 2003)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiorespiratory mortality relative rate was 0.26% (Dominici et al., 2004)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiorespiratory mortality relative rate was 0.31% (Dominici et al., 2004)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality relative rate was 0.17% (Roberts and Martin, 2006)
					United States	$PM_{2.5}$	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality increase was 11.4% (Holloman et al., 2004)
					United States	$PM_{2.5}$	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality increase was 6.0% (Fuentes et al., 2006)
					United States	$PM_{2.5}$	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality association 0.94% (Franklin et al., 2007)
					United States	$PM_{2.5}$	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Stroke mortality association 0.94% (Franklin et al., 2007)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Circulatory mortality increased 3.58% for individuals with pre-existing secondary respiratory conditions (DeLeon et al., 2003)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Circulatory mortality increased 4.2% for individuals with pneumonia (DeLeon et al., 2003)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Circulatory mortality increased 3.2% for individuals with Chronic obstructive pulmonary disease (DeLeon et al., 2003)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Heart disease mortality association 0.65% (Zeka et al., 2006)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Stroke mortality association 0.65% (Zeka et al., 2006)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Stroke mortality association when secondary pneumonia present 1.74% (Zeka et al., 2006)
					Europe	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality association 0.76% (Analitis et al., 2006)
					Europe	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality association 1.21% (Biggeri et al., 2005)
					Europe	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality association 1.06% (Touloumi et al., 2005)
					Europe	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality increased risk 2.4% (Ballester et al., 2002)
					Italy	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Out-of-hospital coronary deaths overall risk 2.8% (Forastiere et al., 2005)
					Finland	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Cardiovascular	Cardiovascular mortality - nonsignificant - 0.63% (Penttinen et al., 2004)
					Windsor, ON	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Respiratory hospitalizations associated 5.34% (Luginaah et al., 2005)
					Toronto	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Increase in respiratory hospitalizations in children 15.7% (Lin et al., 2005)
					Toronto	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Increase in respiratory hospitalizations in boys 19.5% (Lin et al., 2005)
					Vancouver	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Respiratory hospitalizations associated 2.0% (Fung et al., 2006)
					Vancouver	$PM_{10-2.5}$	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Respiratory hospitalizations associated 4.9% (Fung et al., 2006)
					Vancouver	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Chronic obstructive pulmonary disease hospitalizations associated 15.9% (Yang et al., 2005)
					Vancouver	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Chronic obstructive pulmonary disease hospitalizations associated 16.5% (Chen et al., 2004)
					Vancouver	$PM_{2.5}$	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Chronic obstructive pulmonary disease hospitalizations associated 20.9% (Chen et al., 2004)
					London, ON	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Asthma admissions associated 9.3% (Fung et al., 2004)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Chronic obstructive pulmonary disease hospitalizations increased 1.61% (Dominici et al., 2006)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Respiratory tract hospitalizations increased 1.39% (Dominici et al., 2006)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Chronic obstructive pulmonary disease hospitalizations increased 1.47% (Medina-Ramon et al., 2006)
					United States	PM_{10}	ambient air	Increase of 10 $\mu g/m^3$	**Chronic**	Respiratory	Pneumonia hospitalizations increased 0.84% (Medina-Ramon et al., 2006)

Health Benefits of Decreased Wood Smoke Emissions											
Canadian Smog Science Assessment	Health Canada	2013	Review	Assess the effects of smog on human health	United States	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Bronchiolitis in premature infants associated 41% (Karr et al., 2006)
					United States	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Pneumonia hospitalization excessive risk 3.8% (Zanobetti and Schwartz, 2006)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Cardiopulmonary hospitalizations increased 0.61% (Arena et al., 2006)
					Italy	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Respiratory hospitalizations increased 0.73% (Biggeri et al., 2006)
					France	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Respiratory hospitalizations associated 1.7% (age 0-14) (Eilstein et al., 2004)
					France	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Respiratory hospitalizations associated 1.4% (age over 65) (Eilstein et al., 2004)
					Italy	Total suspended particles	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Asthma hospitalizations increased 1.8% (Migliaretti and Cavallo 2004)
					Norway	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Respiratory disease hospitalizations increased risk 3.17% (Oftedal et al., 2003)
					Australia	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Highest risk for pneumonia and acute bronchitis (age 1-4) 6.2% (Barnett et al, 2005)
					Australia	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Respiratory disease increase 2.0% (Hinwood et al, 2006)
					Australia	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Pneumonia increase 5.1% (Hinwood et al, 2006)
					Australia	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Asthma hospital admissions increase 3.0% (Hinwood et al, 2006)
					Windsor, ON	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Cardiac disease hospital admissions associated 0.48% (age over 65) (Fung et al., 2005)
					United States	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Cardiovascular hospitalizations risk of admission 1.28% (Dominici et al., 2006)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Ischemic stroke admissions risk 0.45% (Wellenius et al., 2005)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Myocardial infraction hospital admissions increased risk 0.65% (Zanobetti and Schwartz, 2005)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Cardiopulmonary hospitalizations associated 0.61% (Arena et al., 2006)
					Boston	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Myocardial infraction hospital admissions associated 5.2% (Zanobetti and Schwartz, 2006)
					Baltimore	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Time of onset of symptoms increased 7.38% (Symons et al., 2006)
					Washington	$PM_{2.5}$	ambient air	Increase of 13.8 μg/m^3	**Chronic**	Cardiovascular	Cardiac arrest (all subjects) with supraventricular tachycardia odds ratio 1.55 (Sullivan et al., 2006)
					Washington	$PM_{2.5}$	ambient air	Increase of 13.8 μg/m^3	**Chronic**	Cardiovascular	Cardiac arrest (in smokers) with supraventricular tachycardia odds ratio 12.80 (Sullivan et al., 2006)
					Europe	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Cardiovascular disease admissions increased risk 0.91% (Ballester et al., 2006)
					Europe	Total suspended particles	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Cardiovascular disease admissions increased risk 0.07% (Ballester et al., 2006)
					Europe	Total suspended particles	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Heart disease admissions increased risk 0.45% (Ballester et al., 2006)
					Italy	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Cardiovascular hospital admissions increased risk 0.77% (Biggeri et al., 2005)
					France	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Positive, non-significant associations between PM_{10} and cardiovascular outcomes (Eilstein et al., 2004)
					Europe	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Increased risk of cardiac readmissions 2.1% (von Klot et al, 2005)
					Australia	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Hospital admissions increases for cardiac disease (over 65) 5.08% (Barnett et al, 2005)

Article title	Article author	Year	Publication Type	Article quick summary	Location	Contaminant	Source	Exposure Level	Exposure Duration	Health Impact Category	Health Effect
Health Benefits of Decreased Wood Smoke Emissions											
Canadian Smog Science Assessment	Health Canada	2013	Review	Assess the effects of smog on human health	Australia	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Hospital admissions increases for cardiac failure (over 65) 9.75% (Barnett et al, 2005)
					Australia	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Hospital admissions increases for Ischemic heart disease (over 65) 4.27% (Barnett et al, 2005)
					Australia	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Hospital admissions increases for myocardial infraction (over 65) 7.3% (Barnett et al, 2005)
					Australia	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Hospital admissions increases for total cardiovascular disease (over 65) 3.36% (Barnett et al, 2005)
					Australia	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Hospital admissions increases for cardiac disease (over 65) 1.47% (Barnett et al, 2005)
					Australia	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Hospital admissions increases for cardiac failure (over 65) 4.56% (Barnett et al, 2005)
					Spokane Washington	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Excessive risk in emergency room visits for respiratory disease - 1.7% (Schreuder et al., 2006)
					Italy	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	No relation between daily emergency room visits and daily PM_{10} levels (Vegni and Ros, 2004)
					Spain	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Significant increase in children's emergency room visits for bronchitis (Linares et al., 2006)
					Cleveland	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Summertime asthma emergency room visits marginal association (2.3%) (Jaffe et al., 2003)
					Europe	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Asthma emergency room visits excess risk - 3.9% (Galen et al., 2003)
					Melbourne	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Asthma emergency room visits excess risk - 2.5-4.7% (Erbas et al., 2005)
					United States	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Chronic obstructive pulmonary disease emergency room visits association - 1.8% (Peel et al., 2005)
					United States	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Respiratory	Chronic obstructive pulmonary disease emergency room visits association - 1.5% (Peel et al., 2005)
					United States	PM_{10}	ambient air	Mean daily ambient- 27.9 μg/m^3	**Chronic**	Respiratory	Pneumonia emergency room increased risk associated - 8.7% (Peel et al., 2005)
Canadian Smog Science Assessment	Health Canada	2013	Review	Assess the effects of smog on human health	United States	$PM_{2.5}$	ambient air	Mean daily ambient- 9.2 μg/m^3	**Chronic**	Respiratory	Not significantly associated with pneumonia emergency room visits (Peel et al., 2005)
					Canada	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Positive but non-significant increase in ischemic stroke - 7.8% (Villeneuve et al., 2006)
					Canada	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Positive but non-significant increase in ischemic stroke - 2.8% (Villeneuve et al., 2006)
					Canada	$PM_{2.5}$	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Positive but non-significant increase in hemorrhagic stroke - 17.4% (Villeneuve et al., 2006)
					Canada	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Positive but non-significant increase in hemorrhagic stroke - 6.1% (Villeneuve et al., 2006)
					Australia	PM_{10}	ambient air	Increase of 10 μg/m^3	**Chronic**	Cardiovascular	Cardiac disease significant risk 1.47% (Jalaludin et al., 2006)
Health Effects of Increases in Wood Smoke Emissions (greater than 10 μg/m^3)											
Article title	**Article author**	**Year**	**Publication Type**	**Article quick summary**	**Location**	**Contaminant**	**Source**	**Exposure Level**	**Exposure Duration**	**Health Impact Category**	**Health Effect**
Ambient woodsmoke and associated respiratory emergency department visits in Spokane, Washington	Schreuder et al	2006	Primary Research - Observational	Vegetative burning more strongly associated with respiratory effects than other sources (including wood smoke)	Spokane Washington	$PM_{2.5}$	Wood combustion	Increase of 10.1 μg/m^3	**Chronic:** air quality data from 1995 - 2002	Cardiovascular	Relative risk of hospital visit between 0.995 - 1.015
										Respiratory	Relative risk of hospital visit between 1.009 - 1.018
Ambient woodsmoke and associated respiratory emergency department visits in Spokane, Washington	Schreuder et al	2006	Primary Research - Observational	Vegetative burning more strongly associated with respiratory effects than other sources (including wood smoke)	Spokane Washington	$PM_{2.5}$	Wood combustion	Increase of 10.1 μg/m^3	**Chronic:** air quality data from 1995 - 2002	Cardiovascular	Relative risk of hospital visit between 0.995 - 1.015
										Respiratory	Relative risk of hospital visit between 1.009 - 1.018
Using $PM_{2.5}$ concentrations to estimate the health burden from solid fuel consumption,, with application to Irish and Scottish homes	Galea et al	2013	Primary Research - Observational	Study estimates the potential population health burden from exposure to combustion-derived particulate air pollution in domestic settings in Ireland and Scotland	Ireland and Scotland	$PM_{2.5}$	Wood smoke	Estimated 2.11 μg/m^3 over baseline	**Chronic:** tens of years	Mortality	Additional annual cases of all-cause mortality - 21
										Respiratory	Additional annual cases of chronic bronchitis - 55
										Respiratory	Annual lower respiratory tract symptom days (including cough) - 30,100
										Respiratory	Annual restricted activity days - 38,000
										Cardiovascular	Additional annual cases of cardiovascular hospital visits - 4
										Respiratory	Additional annual cases of respiratory hospital visits - 9
Health Effects of Increases in Air Pollution Concentrations (greater than 10 μg/m^3)											
Article title	**Article author**	**Year**	**Publication Type**	**Article quick summary**	**Location**	**Contaminant**	**Source**	**Exposure Level**	**Exposure Duration**	**Health Impact Category**	**Health Effect**
Effects of ambient air pollution on non-elderly asthma hospital admissions in Seattle, Washington, 1987 - 1994	Sheppard et al.,	1999	Primary Research - Observational	PM and carbon monoxide jointly associated with asthma admissions	Seattle	PM_{10}	ambient air	Increase of 19 μg/m^3	**Subchronic:** April - October	Respiratory	Increase in rate of asthma hospital admissions - 4-5%
						$PM_{2.5}$	ambient air	Increase of 11.8 μg/m^3		Respiratory	Relative rates of asthma hospital admissions - 1.04
						coarse PM	ambient air	Increase of 9.3 μg/m^3		Respiratory	Relative rates of asthma hospital admissions - 1.04
Effects of ambient air pollution on symptoms of asthma in Seattle-Area children in the CAMP study	Yu et al.,	2000	Primary Research - Observational	Effects of PM and carbon monoxide on asthma symptoms	Seattle	Carbon monoxide	ambient air	Increase of 1 ppm	**Subchronic:** 58 days	Respiratory	Increase in asthma symptoms - 30%
						PM_1	ambient air	Increase of 10 μg/m^3		Respiratory	Increase in asthma symptoms - 18%
						PM_{10}	ambient air	Increase of 10 μg/m^3		Respiratory	Increase in asthma symptoms - 11%
Canadian Smog Science Assessment	Health Canada	2013	Review	Assess the effects of smog on human health	Los Angeles	concentrated ambient particles	experimentally generated	200 μg/m^3	**Acute**: 2 hours	Respiratory	no changes in lung function or respiratory symptoms during exercise observed (Gong et al., 2004, 2005)
					Toronto	concentrated ambient particles	experimentally generated	150 μg/m^3 as $PM_{2.5}$ and ozone 120 ppb	**Acute:** 2 hours	Cardiovascular	significant brachial artery vasoconstriction (Brook et al., 2002)
					United States	PM_{10}	ambient air	Mean daily ambient- 27.9 μg/m^3	**Chronic**	Respiratory	Pneumonia emergency room increased risk associated - 8.7% (Peel et al., 2005)

Article title	Article author	Year	Location	Type of publication	DOI/URL	Article quick summary	Health / Psychosocial / Economic Endpoint	Notable findings/associations	Description of association	Equity effects or populations to note?
Modeling of time-resolved light extinction and its applications to visibility management in the Lower Fraser Valley of British Columbia	So et al	2015	Lower Fraser Valley, BC		10.1080/10962247.2015.1010750		Visibility		"Results indicate that to achieve a perceptible visibility improvement of 1.0 dv, the average PM2.5 concentration would have to decrease by 0.8 μg/m3, or a 17% reduction from baseline conditions. To achieve a visibility improvement of 2 dv, the average PM2.5 concentration would have to decrease to 3.0 μg/m3, representing an approximate 30% reduction compared to current levels" Modelling suggests that a 10% reduction in average pm2.5 concentrations would reduce "very poor" visibility daylight hours by 50%.	
Use of residential wood heating in a context of climate change: a population survey in Québec (Canada)	Bélanger et al	2008	Quebec				Behaviour		Cites relationship between atmospheric pollutants and increase in the number of visits to emergency rooms, hospitalizations, health care costs, absenteeism, the reduction in the labour force participation rate, as well as premature death. Popularity for residential wood heating is growing in Canada, and prolonged power outages (in 1998) are seen to have a significant role on this effect in Quebec. Article cites that the Department of Natural Resources suggests that wood heating is a good method to cope with winter storms. Major relevant survey results are as follows: - Respondents are more likely to use wood as a primary or secondary sources of energy if they are of a high income (cut off is $45,000 or greater), are between 35-64 years of age, speak French (only or in addition to another language), lived with children, lived with other people. - More people heat with wood in peripheral communities than urban centres.	
Health impact assessment: Potential effects of wood burner restrictions on wood burning households in Christchurch	Canterbury District Health Board	2014	Canterbury, NZ	Other (Health Impact Assessment)	www.cph.co.nz/wp-content/uploads/ecanairplanhia.pdf	Evaluation of wood burner bans on poorer populations. The focus is on health effects of housing with attention to heating and cold homes.	Cold homes Food security Employment and education Fuel poverty	There can be risks associated with cold homes, particularly for vulnerable groups. There can be food security issues related to household heating. Employment and education issues Fuel poverty is defined as households spending more than 10% of income of energy to heat the home.	**Issues related to cold homes:** • Temperatures below 16°C, particularly in the presence of high humidity, are associated with adverse health consequences and temperatures below 12°C are a health risk for vulnerable groups. • Cold homes can have mental wellbeing effects. Children living in cold homes are more likely to have mental health issues (anxiety and depression). Other issues include lack of control for a tenant and financial stress over maintaining an appropriate temperature. Improvement of thermal quality is associated with improved mental wellbeing and self esteem. Families spend more time with each other inside, when a home is an appropriate temperature (positive effects for child education, play and enthusiasm for school attendance) • Household crowding can occur in cold homes. This can affect infectious disease transmission, violence/aggression and mental health. **Food Security:** • High heating cots many affect the ability to afford basic necessities (food).- Association found between food insecurity and seasonally high heating/cooling costs. • Severe energy insecurity associated with childhood developmental issues. **Employment and Education:** • Health conditions due to a cold home can lead to absenteeism (children and adults).	• Cold homes affect elderly/children, among other vulnerable groups. • Food security issues emerge among low-income households. • Ban on wood burners could affect low income burning households, households within fuel poverty thresholds (can include middle and high income households depending on cost of heating homes), households with individuals who have pre-existing health conditions that may make them vulnerable, and rental households who have less control over heating.
Health impacts of cold homes and fuel poverty	Marmot Review Team	2011	UK	High quality report	http://www.instituteofhealthequity.org/projects/the-health-impacts-of-cold-homes-and-fuel-poverty	Evaluates health impacts of cold homes and fuel poverty	Cold housing Fuel Poverty Economic stimulation Mental health	Cold housing has negative impacts on children Fuel poverty negatively affects food security through dietary opportunities and choices Cold housing can impact accidents and injuries through reduced dexterity Investing in energy efficiency of homes can stimulate the economy and create opportunities for improving skills in the construction workforce There are mental health effects associated with cold homes	**Fuel Poverty** • Fuel poverty is not the same as being income poor. Fuel poverty is more easily changed than income poverty (through increase income such as the Winter Fuel Payment, to regulate fuel pricing, and to improve energy efficiency of homes). One of the most sustainable ways to address fuel poverty is through building energy efficient homes. • Private rented homes are more likely to be fuel poor. Fuel poverty is more common in rural English communities. • Effects of fuel poverty are related to specific health conditions. • Fuel poverty is detrimental to mental health through financial stress. Fuel poverty and ill health can also exacerbate each other. **Cold homes** • Damp and mold conditions more likely to emerge. • As bedroom temperatures rise, a study found that occupants are more likely to avoid depression. • There can also be social isolation, as older people may not want to go out when it is cold to a cold home, or are embarrassed to invite people over to a cold home. • People may associate warm homes with better social relationships and mental health. • 20% of survey respondents to a survey reported improving their cooking in warmer homes since kitchens became comfortable to work in.	**Children:** cold housing has negative effects on child educational attainment, emotional well-being and resilience. Children living in cold homes also suffer through infant weight gain, hospital admissions, developmental status, severity/frequency of asthmatic symptoms, can be more likely to contract meningitis, have respiratory problems, experience long-term ill-health and disability, slowed physical growth and cognitive development. **Adolescents:** Negative mental health effects of cold homes. **Adults:** Effects of physical health, well-being self-reported health (particularly for vulnerable and those with pre-existing health conditions). **Older people:** Increased mortality risk, physical health and mental health effects. A cold house increases risk of falls (leading to periods of immobility where it is harder to keep warm). Those without access to social housing have fewer resources and less resiliency to deal with cold homes. Excess winter deaths- not correlated with lower socioeconomic status (these people are more often than not in social housing)

Article title	Article author	Year	Location	Type of publication	DOI/URL	Article quick summary	Health / Psychosocial / Economic Endpoint	Notable findings/associations	Description of association	Equity effects or populations to note?
Health impact and monetary cost of exposure to particulate matter emitted from biomass burning in large cities	Sarigiannis et al.	2015	Thessaloniki, Greece	Primary research-observational	https://www.researchgate.net/publication/275410923_Health_impact_and_monetary_cost_of_exposure_to_particulate_matter_emitted_from_biomass_burning_in_large_cities	Describes health impacts of residential wood smoke in Greek city	Mortality Economic costs	There are significant economic costs due to PM exposure from biomass burning for both mortality (in the billion Euro range) and morbidity (in the millions of Euros range).	Examined biomass for home heating. Compared with the warm season (no heaters in use), the winter season was associated with 200 premature deaths in a population of around 900,000 people, equating to 3,540 years of life lost. Using a willingness-to-pay model, the authors estimated the cost of morbidity/mortality from residential biomass burning. Cost components included: • resource costs (i.e. medical costs for health services, insurance and out-of-pocket expenses); • opportunity cost including reduced productivity (e.g. absenteeism or presenteeism) and reduced leisure/unpaid work times; • dis-utility (other social and economic costs such as restricted or reduced enjoyment of leisure activities, pain, anxiety, concern/inconvenience to family members). Monetary costs related to annual mortality attributed to PM exposure were in the range of a billion Euros, and remained high when alternate costing methodologies were applied (value of statistical life for value of a life year methods). Cardiovascular and respiratory morbidity costs are in the range of millions of Euros. Exact figures were not provided in the article. Authors conclude that there could be large economic benefits to change the fuel mix for residential heating, due to differences in particulate emissions between biomass combustion and competing fuels and heating space systems. Authors also note that the poor socioeconomic situation in Greece would have exacerbated the impact due to biomass (wood) being a more affordable heating option, and families would be more predisposed to health conditions due to lower SES (higher asthma rate, more smoking, poorer nutrition, higher alcohol intake....). They could also be less likely to seek preventative care.	
Spatial variability and population exposure to PM2.5 pollution from woodsmoke in a New South Wales country town	Robinson et al.	2007	Australia	Primary research-observational	internal only	Some health and economic impacts	Economic costs of wood burning	In a population where 55% of residents used solid fuel heaters, 7% of total mortality was attributed to these heaters.	Study took place in a town in which 55% of residents used solid fuel heaters. Applying estimates (from other researchers' studies) of an increase of 6% in total mortality for each increase of 10 mg per m3 in PM2.5 pollution, the researchers attributed a 7% of total mortality (10% in cardiopulmonary mortality, 16% in lung cancer mortality) to woodsmoke in this specific population. Study cites a publication that estimated that that in Australia, the cost of a premature death from air pollution was estimated at AU$1.3 million (US$0.97 million). Fisher et all 2005 estimate that emissions from cosmetic solid fuel heaters in Christchurch, NZ lead to 124 premature deaths per year, costing $89 million (USD)	
Air pollution in Australia: review of costs, sources and potential solutions	Robinson	2005	Australia	Systematic review	*Internal*	Some health and economic impacts	Policy options	Reduced taxes for low polluters and high taxes for high polluters which is comparable to estimated health costs would efficient and equitable to protect community health	Annual cost of wood heater emissions: cost per wood heater $2,407 AU. Provides policy options. Community education programs that discuss proper operation have had little effect. Suggests "polluter-pays" options, which could fund woodheater licenses. Smoke patrol, health care costs, buyback schemes.	
Residential heating with wood and coal: health impacts and policy options in Europe and North America	Chafe et al	2015	North America/Europe (from WHO)	High quality report	http://www.euro.who.int/__data/assets/pdf_file/0009/271836/ResidentialHeatingWoodCoalHealthImpacts.pdf	WHO overview of woodburning and coal, with specific implications for policy in Europe and North America	Education Policy Burden of disease	Policy options- no burn days, incentives for switching.... These are discussed in more depth but out of scope for this review.	Household wood combustion for heat is on the rise in some countries due to government incentive, high cost of other energy sources, and public perception that it is a 'green' option. These are expected to increase if there is no push for modern and efficient wood heating devices. Some families use solid fuels during times of economic hardship. In the USA, residential heating with wood grew by 34%, particularly in low and middle income households from 2000-2010. In 2010 there were an estimated 61,000 deaths in Europe due to PM2.5 exposure from heating with solid fuels. In North America (High income) DALYs increased from 140,000 (1990) to 160,000 (2010) (NOTE: THIS IS SPECIFIC TO OUTDOOR EXPOSURE) There has been increased rates of hospital admissions and emergency rooms visits associated with wildfires and severe respiratory effects. In Ireland, ban on coal improved health. Led to a statistically significant decrease in respiratory deaths (keeping in mind that there is higher use of woodburning/coal for heat in Europe than in North America). Canadian Council of Ministers of the Environment evaluated 12 stove change efforts, and found program limitations in regards to the cost of new technologies (supported use of regulation to curb sale of high-emission appliances). EPA has a Burn Wise program (teaches about what wood to burn, as well as alternatives). A study in Australia found that the main barriers to reducing wood smoke were poor operation of wood heaters, mismanagement of firewood, and lack of knowledge regarding health effects. Overall, education programs have moderate success. Education needs to focus on changing the perception of woodburning from 'cozy' to show real harm and health effects.	

Article title	Article author	Year	Location	Type of publication	DOI/URL	Article quick summary	Health / Psychosocial / Economic Endpoint	Notable findings/associations	Description of association	Equity effects or populations to note?
Supplemental Economic Impact Statement for Vermont's Proposed Rule on Outdoor Wood-Fired Boilers	Robert Black	2006	Vermont, USA	Other- Environmental impact statement		Economic effects with health connections, mainly limited to outdoor wood-fired boilers	Economic effects (positive and negative)	Outdoor wood boilers can be placed and designed to reduce health effects, and thus (base on willingness to pay methods and cost of illness), have economic benefits to the owners (same benefits extend to other residents). Visual impacts could affect property values. due in part to perceived or real health impacts.	Outdoor wood-fired boiler effects for owners: availability of on-site wood is an advantage as a heating fuel (possible in rural areas). However, this should not be seen as 'free'- and instead has an opportunity cost. For a wood stove, authors predicts a $225 price per unity (although process can be volatile due to the market), and that it operates at a 68% or 72% efficiency (for an indoor wood stove). This is lower than an outdoor wood boiler or oil forced air, and comparable with other gas and oil alternatives. There may be economic impacts through health benefits. outdoor wood boilers (depending on design and location) can reduce exposure and health risks. can benefit cardiovascular and respiratory related hospital admissions, premature mortality, asthma, and other respiratory symptoms. Outdoor wood-fired boiler effects for neighbours: Exhibit 5-3 summarized willingness-to-pay (WTP) and cost-of-illness (COI) for health effects from PM related health effects (not specific to PM from woodburning). However, notable that willingness to pay for premature morality is $5.5 million, $2,400 for respiratory hospital admissions, and $2,400 for hospitalization for cardiovascular symptoms. The COI for the respiratory hospital admissions and cardiovascular hospital admissions are respectively; $6,623-$39,000 and $22,000-$158,000 (values in USD, range depends on study). If manufacturers were to meet upgraded standards for outdoor wood-fired boilers, the cost (although highly variable) would yield a total annual cost of #380,000 for retailers, equivalent to a 7% decreased in premature mortality, elimination of 3-15 cardiovascular hospitalizations, and elimination of 10-50 respiratory hospitalizations. Nuisance effects of smoke include health effects (only difficulty breathing is given as an example). Smoke is anecdotally reported to affect property values, and authors connect this change to real or perceived health effects..	
The Georgia Basin - Puget Sound Airshed Characterization Report 2014, Chapter 14. Health and Socio-Economic Impacts of Poor Air Quality	Vanderwal et al (for Environmental and Climate Change Canada)	2014	Georgia Basin, Canada	High quality report			Hospital admissions Burden of disease Economic costs (health care, tourism, other industries)	Includes economic costs specific to Greater Vancouver Area (e.g. from visibility, healthcare burned and burden of disease from pollution and woodsmoke, and industrial production).	Tables 14.1 Summarizes several health effects of air pollutants. Relevant for this review are: increased cardiovascular emergency department and hospital visits from PM; increase respiratory admissions (bronchiolitis, COPD) from woodsmoke. There are as many deaths in the lower mainland from air pollution as there is from HIV, accidental falls or traffic accident.. Non accidental death in greater Vancouver increased by 8.3% on high-pollution days. A 25% reduction in PM10 could avoid more than 2700 premature deaths and 33000 emergency rooms visits over a 30 year period. **Socioeconomic impacts related to poor air quality** Health impacts: Estimated that a 10% improvement in ground level ozone and PM 2.5 over a 5 year average, savings in west lower Fraser Valley would be $208 million and in east Lower Fraser Mainland would be %30.1 million (2003 Canadian dollars, undiscounted). This is in health care savings as well as other benefits. Reduced visibility from air pollution may have significant impacts on regional tourism revenues. Depending on visibility, loss in the greater Vancouver Area was estimated at 4.03-7.45 million. Losses could also accumulate in terms of reduced return visits and long-term reputation of poor visibility. Using a willingness-to-pay model, and considering visibility, health risk and household cost, a study estimated that a 5-20% increase in visual range was valued at $29.38-$48.55 Can per year (in Lower Mainland). Air pollution can also have impacts on agricultural production (however this is mainly due to ozone).Timber industry is also effected by ozone. Air pollutants such as sulphur oxides and nitrogen oxides can lead to water acidification or eutrophication. This could affects tourism activities on impacts lakes, reduce property values, drinking water treatment costs, and reduce fish population thereby affecting the fishing industry. Material soiling can damage surfaces. There is limited literature, but there are costs associated with cleaning residential homes due to changes in PM10.	Seniors, children, pregnant women and individuals with chronic disease at most risk with poor air quality
Ambient woodsmoke and Associated Respiratory Emergency Department Visits in Spokane, Washington	Schreuder	2013	Spokane, WA USA	Primary research-observational	http://dx.doi.org/10.1179/oeh.2006.12.2.147	Article addresses woodburning and vegetative woodsmoke in Spokane	Hospital admissions	Put simply, respiratory hospital admissions increased with increased vegetative burning	Methods (helpful for this study): Source marker compounds were used to assess the associations between atmospheric concentration of these compounds and daily cardiac hospital admissions and/or respiratory emergency department (ED) visits. Population is small and pollutions levels low; however, this study was conducted over 7 years to compensate. 2% increase in respiratory ED visits for an interquartile range change in total carbon for the vegetative burning marker (the only one attributable to woodsmoke). 0.6% increase in respiratory ED visits per llg/ m3 of woodsmoke particle mass (80% carbon).	
Effectiveness of Residential Wood-Burning Regulation on Decreasing Particulate Matter Levels and Hospitalizations in the San Joaquin Valley Air Basin	Yap & Garcia	2014	San Joaquin Valley, USA	Primary research-observational	NA	Exposure and hospital admission after policy to reduce wood burning	Hospital admissions	Hospital admissions for cardiac and respiratory decreased with the introduction of a regulation limiting residential wood burning. The decrease was greater among the elderly than among younger adults.	Hospital admissions for cardiovascular disease (CVD), ischemic heart disease (IHD) and COPD decreased after the introduction of Rule 4901 which limited residential wood burning (public health education, reduction of burning on poor air quality days, reduce emissions from woodburning fireplaces and heaters). Change in disease rates from before to after introduction of legislation: **Adults ages 45-64 :** CVD- 41.0 to 39.9 hospitalizations per 1,000 population IHD- 23.0 to 21.5 hospitalizations per 1,000 population COPD-7.2 to 6.5 hospitalizations per 1,000 population **Elderly ages 65 and over**: CVD- 152.2 to 81.1 hospitalizations per 1,000 population IHD- 60.7 to 31.6 hospitalizations per 1,000 population COPD- 23.7 to 13.7 hospitalizations per 1,000 population Adjusted rate ratios also presented (table 3) for risk of hospitalization, segmented by adult / elderly; rural / urban and CVD/IHD/COPD.	Elderly
Health impacts of anthropogenic biomass burning in the developed world	Sigsaard et al	2015	Canada, USA, Europe, Australia	Primary research-observational	10.1183/13993003.01865-2014		Economic cost		Cited a study conducted in Denmark that found residential woodsmoke was responsible for 30% of external health costs from air pollution emissions in 2008 (16% of costs in 2000).	

Article title	Article author	Year	Location	Type of publication	DOI/URL	Article quick summary	Health / Psychosocial / Economic Endpoint	Notable findings/associations	Description of association	Equity effects or populations to note?
Residential Use of Wood-Burning Appliances in Canada: Emissions, Health Effects, and Intervention Strategies	E Risk Sciences	2009	Canada	High quality report			Public knowledge/perceptions Health worker perceptions and knowledge	Woodsmoke was not perceived to be a major issue among health agencies interviewed, and complaint received from the public is low.	Many public agencies also report on woodsmoke as a nuisance, as opposed to a threat to health. Local health practitioners may be unaware of health effects from woodsmoke. Information campaigns are not enough to lead to behaviour change regulation seen as most effective. Interview data: Woodburning occurred more frequently in rural than urban areas, and is more common from November-March (or longer in cold regions). Interviewees believe that woodburners used were likely older appliances (not CSA/EPA certified), particularly in older and rural homes. Most common reasons for use include perceptions of cost saving, reliability over utility disruptions, availability due to abundant forests or declining forest health (pine beetle wood), and aesthetics. Because the public may not believe that health issues are related to woodsmoke, some agencies have moved towards emphasizing being a good neighbour, and potential financial benefits (although these are not explained).	
Assessing the Impact of a Wood Stove Replacement Program on Air Quality and Children's Health	Noonan et al	2011	Boston	High quality report		Report presents an investigators' report (by Noonan et al), as well as a critique of this work by the Health Review Committee.	School absences	School absences not associated with daily PM2.5 concentration	**Assessing the impact of a wood stove replacement program on air quality and children's health (Noonan et al, research study within larger report.)** Daily changes in PM2.5 (adjusted for age group of child, wind gust, and day of the week and one day lagged PM2.5 concentration), was not associated with illness-related absences. However, analysis of winters (three before wood-stove change out program and three winters after the change-out program) found the frequency of illness-related absences in middle school children was 3.07% (first 3 winters) and 2.84% (last 3 winters); a 5-µg/m3 reduction in average ambient winter PM2.5 concentration corresponded to a 5.6% reduction in illness-related absence (95% CI = 1.1 to 10.2). Authors find this to be contradictory, and all around inconclusive, and the Health Review Committee does not believe that this is a causal relationship.	
Odor, gaseous and PM10 emissions from small scale combustion of wood types indigenous to Central Europe	Kistler et al	2012	Central Europe	Primary research-observational	10.1016/j.atmosenv.2012.01.044	Odour, gaseous and PM10 emissions in central Europe	Odour		Odour mainly emitted during smoldering. Woodsmoke odour levels more likely to be above thresholds on days during the winder in wood burning communities with poor ventilation. Different wood types do not emit odours with large variances, however odour concentration is higher for softwood species than hardwood.	

Article title	Article author	Year	Location	Type of publication	DOI/URL	Article quick summary	Health / Psychosocial / Economic Endpoint	Notable findings/associations	Description of association	Equity effects or populations to note?
Upper Hunter Wood Smoke Community Research Project	Databuild (for NSW Environment Protection Authority)	2016	Australia	Other (grey research report)		Community attitudes towards wood smoke pollution and household heating choices	Psychosocial connections to wood heaters Economic effects (discussed qualitatively, not quantified).		**Stakeholder Interview (includes government, the Upper Hunter Aus. Quality Advisory Committee, community groups, environment groups and wood heater salesperson):** Woodsmoke is seen publically to not contribute significantly to air quality issues, stakeholders believed that this was due to lack of awareness and reluctance to acknowledge harmful effects. Homeowners may be unable to acknowledge the impact that they as individuals have on air pollution, and prefer to look at larger sources (e.g. coal). **Household focus groups:** Owners were seen to be attached to their wood heaters for emotional and rational reasons- for example the ambiance and the free fuel (due to perception pf wood as a natural, renewable source). Social benefits include bringing households together around a fire. **Drivers to continued use of wood heaters:** **Stakeholder interviews:** Rising cost of utilities (saving money on installation and running costs); Rise in unemployment; Nostalgia and tradition. **Household focus groups:** Convenience, affordability, efficiency (wood heaters heat the whole home, other heaters do not); versatility (can heat water and dry clothes); property maintenance (fire wood from fallen branches), experience (same as nostalgia), aesthetically pleasing, part of 'country life, environmentally friendly. Wood heathers were less appealing to the following groups: younger groups who see wood heaters as a hassle, elderly and disabled, who find heaters difficult, those without access to firewood, those not used to using a wood heater, and those with respiratory problems. A quantitative survey (203 telephone interviews) showed that 96% of survey respondents preferred wood heating.	
2015 Report on the Health Consequences of Wood Smoke	Utah Physicians for a Healthy Environment	2015	Utah			Position piece by a physician group, providing arguments against residential burning	Economic costs Policy		Useful for policy/HIA- EPA woodstoves have never been shown to reduce the amount of the most dangerous components of woodsmoke (characterised as dioxins, furans and PAHs)- there may be higher in some EPA stoves (several citations for this statement) Cited from a report from Families for Clean Air: reliance on wood burning for home heating is rationalized due to high cost for electricity or propane, which has even swayed air regulators. Areas not services with natural gas have been exempted from wood burning restrictions. However, heating a home with electric split ductless heat pump is actually cheaper than heating with natural gas (no ductwork required), and initial cost is comparable with a woodstove. Spit ductless heat pumps can also cool. Bay Area Air Quality Management District estimates that there are more than $1 billion worth of medical expenses that are cause by burning woodsmoke in the Bay Area. Estimated that a single wood fire can cost a neighbour an average $40 in medical expenses.	Pregnant women and children spend more of their time at home than the average person (especially during the winter), and may be exposed to more woodsmoke (no source for this, appears to be from physician experience).

Literature review was also conducted to investigate regulatory and non-regulatory approaches used to manage wood smoke emissions in other jurisdictions. The findings of this review are presented in **Section 4.1** (Policy Initiatives from Select Jurisdictions). Additional socio-economic literature reviewed in also included in the following table.

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APPENDIX B

Summary of Feedback from Local Experts

Summary of Feedback from Local Experts

Regional experts were consulted to provide local context and advice on methodologies, resources, policies decisions/implementation and socio-economic effects. Based on the responses to the interview questions, brief synopses of each interview were compiled.

Synopsis of Interview with Dr. Michael Brauer, UBC

Dr. Brauer mentioned a number of quality papers published in recent years that could be helpful to our research, which were subsequently used. When we discussed our methodology for estimating the potential for health benefits through reduction of wood smoke emissions and our plan to use the AQBAT model, he mentioned that there are some acute studies (that looked at asthma days and restricted activity days) and chronic studies that are not included in AQBAT. Also, he mentioned that AQBAT treats all sources of $PM_{2.5}$ the same, which may not accurately present health effects due to $PM_{2.5}$ from wood smoke alone. When we discussed our concerns about amortizing exposure to wood smoke during the 3-4 month long burning period over a chronic period, he confirmed that he would agree with doing the amortization. Uncertainties he identified with AQBAT were presented in the final report.

Synopsis of Interview with Dr. Lisa Mu, Ken Shaw and Goran Krstic, Fraser Health Authority

Representatives at Fraser Health Authority, Dr. Lisa Mu, Ken Shaw and Goran Krstic, expressed the importance of integrating health effects with socio-economic considerations so that unintended adverse effects to low income families and other reliant on wood heating are not overlooked. They stressed that socio-economic status plays a larger role in health than does exposure to environmental pollutants, including wood smoke. Concern was expressed regarding applying broad regulations on something that is a very localized problem. In discussing our planned methodology (i.e. using AQBAT), Dr. Krstic indicated that uncertainties associated with this methodology need to be presented, along with a presentation of confounding factors (weather, vitamin D, smoking, socio-economic status). They expressed a desire to read the draft report once it was complete.

Synopsis of Interview with Markus Kellerhals, Air Protection, B.C. Ministry of Environment

Mr. Kellerhals provided some insight into implementation of a wood smoke regulation program and stressed the importance of public education and exchange program initiatives. In his experience, people tend to think that the emissions caused by wood smoke aren't as bad as those from other sources. Mr. Kellerhals frequently receives calls from complainants who find their neighbour's wood smoke to be irritating, including disliking the smell of the wood smoke, to the extent that it affects their behaviours, such as avoiding their patio when the neighbour is burning and emitting wood smoke. In his experience, province-wide he has found that low-income households tend to be more reliant of wood burning for heating than high income families. He postulates that this is unlikely to be a factor in Metro Vancouver, given that low income people here do not have ready access to cheap or free wood to burn.

Synopsis of Interview with Sarah Henderson, UBC

Dr. Henderson provided valuable insight into using the AQBAT model. In particular, she mentioned that AQBAT places a great deal of importance on the cost of mortality, which results in an overshadowing of the morbidity endpoints. For instance, effects such as otitus media (middle ear infection) and associated antibiotic costs, or the loss of time and money due to asthmatic children staying home from school, are overshadowed by mortality due to wood smoke emissions. Acute effects are likely to have day-to-day impacts for families and should be emphasized in the assessment. She felt it was important to note that wood smoke is likely a very localized issue, and that burning for residential heating versus burning for aesthetic purposes is even more localized. People burn wood to heat their homes since it's cheap and readily available. Restrictions on wood burning may prove detrimental to lower income families as money that these families would have saved would need to be spent heating their homes and, as such, they would have less money to spend on groceries, rent, etc.

Synopsis of Interview with Ryan Allen, SFU

Dr. Allen provided input on the methodology of quantifying health impacts. He agreed that $PM_{2.5}$ is the best metric for evaluating health effects associated with wood smoke emissions. He mentioned that respiratory effects associated with wood smoke $PM_{2.5}$ may be as serious as from any other source of $PM_{2.5}$, however cardiac effects due to wood smoke emissions may be less serious (although not definitively proven yet). Current research into health effect due to wood smoke emissions is focused on pregnancy/fetal growth/ early lifestage growth and dementia, however these endpoints are not included in the AQBAT model at present. Regarding AQBAT, Dr. Allen mention that there has been significant work on the concentration-response functions; the link between endpoint and exposure has been shown to be nonlinear, with the highest slope at low emission concentrations, which then tapers to a lower slope as emissions increase. As such, the greatest benefits occur at lower $PM_{2.5}$ concentrations. One of the interesting non-health related impacts Dr. Allen mentioned was the impact of wood smoke on stress due to someone else's health state (i.e. sick asthmatic child, pregnant wife).

Synopsis of Interview with Dr. James Lu and Randy Ash, Vancouver Coastal Health

Dr. James Lu and Randy Ash provided insight and additional resources for evaluating health risks due to wood smoke emissions. Dr. Lu recommended accessing http://myhealthmycommunity.org/ as a means of accessing more refined, neighborhood-specific health data. He also provided a brief write-up of the work conducted in Richmond, which looked at $PM_{2.5}$ concentrations relative to emergency room visits due to chronic obstructive pulmonary disease and related conditions such as bronchitis, asthma, and other respiratory diseases. They pointed out that there may be a need to extend policy decisions to include regulations on commercial wood smoke emission sources, such as wood oven pizzerias. Also it was noted that consideration should be given to those that burn wood for heating during power outages in areas that are prone to power outages. Dr. Lu mentioned that the City of Vancouver is pushing to move away from non-renewable energy sources, and that could push people towards wood burning.