EFFECTS OF HOUSEHOLD AIR POLLUTION: A SYSTEMATIC REVIEW

THE EFFECTS OF HOUSEHOLD AIR POLLUTION ON CHILDHOOD ASTHMA, ACUTE LOWER RESPIRATORY TRACT INFECTION AND LUNG FUNCTION

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LAY ABSTRACT

Household Air Pollution (HAP) refers to the pollution of indoor air caused by the combustion of solid fuels, such as biomass, for the purposes of heating and cooking. According to the World Health Organization (WHO), 2.6 billion people are exposed to HAP daily. Women and children are especially at high risk of exposure, due to the time spent indoors. This places them at a higher risk of adverse respiratory outcomes, such as Acute Lower Respiratory Tract Infection (ALRI), asthma, Chronic Obstructive Pulmonary Disease (COPD) and reduced lung function. This thesis document investigates the association between HAP and the adverse respiratory outcomes, namely lung function, ALRI and asthma in children. It was found that HAP is associated with a decrease in childhood lung function growth, and an increased risk of the incidence of ALRI. However, there was no clear association between the incidence of asthma and HAP. The results of the systematic reviews justify a transition from the use of solid fuels to clean fuels and technologies.

ABSTRACT

Introduction and Rationale: Household Air Pollution (HAP) refers to the pollution of air in the indoor environment, from the combustion of solid fuels such as biomass and coal. The World Health Organization (WHO) estimates that 2.6 billion people today are exposed to HAP daily. Women and children tend to be at a higher risk of exposure due to their increased time spent indoors. This can result in a range of adverse cardio-respiratory outcomes such as asthma, Acute Lower Respiratory Infection (ALRI) and Chronic Obstructive Pulmonary Disease (COPD). This thesis document investigates the association between HAP and the adverse respiratory outcomes, namely lung function, ALRI and asthma in children.

Methodology: Systematic Reviews were conducted to synthesize the effect of HAP on lung function, ALRI, and asthma. The lung function outcome was synthesized in a narrative manner, while the pooled estimates for the ALRI and asthma outcomes were synthesized by meta-analysis.

Results: Exposure to HAP is associated with decreased lung function growth, and an increased risk of the incidence of ALRI in children. No association was noted between HAP exposure and the incidence of asthma in children.

Conclusion: The effect of HAP on childhood growth of lung function and the incidence of ALRI provides evidence justifying the universal transition to cleaner fuels and technologies, such as electricity and natural gas.

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LIST OF ABBREVIATIONS AND SYMBOLS

Acute Lower Respiratory Infection - ALRI

Chronic Obstructive Pulmonary Disease - COPD

Disability Adjusted Life Year – DALY

Household Air Pollution – HAP

International Energy Agency – IEA

Low- and Middle- Income Countries - LMIC

Particulate Matter – PM

Risk of Bias – ROB

Risk Ratio – RR

Odds Ratio - OR

Sustainable Development Goal – SDG

United Nations - UN

World Health Organization – WHO

World Bank - WB

LIST OF APPENDICES

DECLARATION OF ACADEMIC ACHIEVEMENT

This thesis has been prepared in fulfillment of the requirement for the degree of Master of Science in Global Health. I drafted this thesis manuscript under the direction and supervision of Dr. Kurmi. Dr. Kurmi, and Laura Banfield served as supervisory committee members Dr. Kurmi provided primary supervision in all aspects of this research project, including the project proposal, study design and thesis drafts. Laura Banfield provided guidance on developing and implementing a search strategy. Dr. Om Kurmi provided training and feedback with the study design and statistical methods/tests used in this thesis. All supervisory committee members provided feedback on the research proposal and thesis draft.

CHAPTER 1- INTRODUCTION

1.1 Outline

This paper-based 'sandwich' thesis includes my graduate research work to satisfy the requirements for a master's in science (M.Sc.) degree in Global Health. This thesis intends to contribute to an important study, summarizing the effects of Household Air Pollution (HAP) on lung function in children, and on the incidences of childhood asthma, and acute lower respiratory tract infection. In this introductory chapter, I provide a narrative summary of the literature on HAP, the outcomes of the study and convey this thesis' objective. My research findings are presented as original manuscripts of two systematic reviews. The first manuscript has been published in a peer reviewed scientific journal; and the second will be submitted for peer review in August 2022.

1.2 Background

In this study, HAP refers to the pollution of household air, caused by the combustion of solid fuels, for cooking and heating purposes. The term solid fuel includes biomass and coal. Other indoor air pollutants, such as tobacco smoke exposure, dust, ambient air pollution, and allergens are excluded from this definition of HAP.

HAP is caused by the incomplete, and inefficient combustion of solid fuels, most commonly occurring in poorly ventilated settings. Using solid fuels results in high indoor concentrations of fine particulate matter (PM). Homes that cook using solid fuels can contain particulate matter greater than 1000μg/m^3, with even higher values known to have been reported (Balakrishnan et al., 2013; Smith et al., 2014). Such levels of exposure are at least an order of magnitude greater than the greatest concentrations noted in the ambient air of the developed world (Bruce et al., 2000; Diette et al., 2012). For reference, the WHO air quality guideline threshold for $PM_{2.5}$ exposure over a 24 hour period is 15μg/m^3 (WHO, 2021). Moreover, depending on the type of solid fuel used, several toxic compounds can be produced during their combustion, such as carbon monoxide, nitrogen dioxides, formaldehyde, benzene, 1,3 butadiene and benzo[α]pyrene et cetera (Warwick & Doig, 2004).

Although the weight of toxicological literature on HAP is lower, it has been suggested that the mechanism(s) through which solid fuel smoke causes adverse impact is likely similar to that of tobacco smoke, and other combustion-PM-related pathogenic processes (Mehra et al., 2012). Therefore, it is thought that the biomass smoke elicited-oxidative stress in the airways and alveoli leads to a response of the innate immune system, an inflammatory response (Mondal et al., 2018). However, other organ systems can also be impacted when the local inflammatory response spills into the systemic circulation. This can cause an increased risk of respiratory tract infections and adverse cardiovascular outcomes among other sequalae (Lee et al., 2020; Whitehouse et al., 2018)

Indeed, the exposure to HAP from the combustion of solid fuels remains a leading risk factor for the global disease burden (Bennitt et al., 2021). Among the global burden of diseases, HAP remains fourth amongst all risk factors (and first amongst environmental and occupational risks), in the list of risks (by Disability Adjusted Life Years, or DALY) in the age group 0-9 years. Among all age groups, HAP was the tenth amongst risk factors by age-standardized DALY in 2019 (4^{th} in 1990). This represents a higher DALY compared to alcohol use, high body mass index, unsafe water, and poor sanitation et cetera. In 2019, by one estimate, 2.31 million global deaths were attributable to HAP exposure and accounted for 4% of all deaths (Bennitt et al., 2021). According to the WHO, 3.8 million pre-mature deaths annually, are attributable to HAP (WHO, 2022). Of these, 27% are due to pneumonia, 27% from ischemic heart disease, 20% from Chronic Obstructive Pulmonary Disease (COPD), 18% from stroke, and 8% from lung cancer (WHO, 2022).

Methane emitted by the combustion of solid fuels is a powerful pollutant contributing to climate change. Moreover, the continued use of solids fuels impacts health equity, development, and climate change. Women and children are not only at higher risk of developing adverse outcomes due to higher exposure and losing considerable time that could be used for school, or other income generating activities (Austin & Mejia, 2017) .

1.2.1 ALRI and HAP

Acute Lower Respiratory Infections, and their resulting pneumonia are the primary cause of death among children younger than five (WHO, 2022). According to the WHO, exposure to HAP is said to double the risk of childhood pneumonia and is responsible for 45% of all pneumonia deaths under the age of 5 (WHO, 2022). Notably, the incidence and mortality from childhood pneumonia are the greatest in countries and regions with the highest use of solid fuels.

The observational epidemiological literature on childhood ALRI and the exposure to HAP is derived primarily from case-control studies, and some cohort studies. The overall estimate of the risk of ALRIs due to the exposure to HAP from a meta-analysis of 24 studies published before 2008 was a pooled odds ratio (OR) of 1.79 for children younger than five years, and 1.96 for children younger than two years (Smith et al., 2014).

1.2.2 Asthma and HAP

Asthma is a complex disease, influenced by various of genetic and environmental factors. Childhood asthma is the most common chronic disease in children, with its prevalence estimated to be between 2% and 40% by country (Paciência et al., 2022). The indoor air pollutants thought to modify the severity of asthma symptoms include PM exposure, nitrogen and sulfurous oxides, allergens, mold et cetera (Breysse et al., 2010). Thus, the plausibility of an increased risk of asthma exists, due to the airway-irritant effects of solid fuel smoke.

However, the risk of the incidence of asthma due to HAP remains unclear, as the evidence appears to be mixed. A systematic review examining the effects of biomass smoke on childhood asthma pooled the risk estimates from four studies involving children, generating a pooled OR of 0.50 [95% CI: 0.12-1.98] (Po et al., 2011). However, recent large cross-sectional studies have shown mixed results (Balmes, 2019; Fernandes et al., 2018; GBD 2015 Chronic Respiratory Disease Collaborators, 2017). Therefore, further research is needed to understand the relationship between HAP and childhood asthma, examining outcomes of both asthma incidence and exacerbations outcomes.

1.3 Use of Solid Fuels, and Global Exposure to HAP

The combustion of wood is considered a crucial moment in the human evolution into the bipedal human condition (Wrangham, 2009). With the advent of organized agricultural activity around 10,000 years ago, agricultural residue, including dried animal dung, was used as a solid fuel. Beginning approximately 1,000 years ago, coal has been used as a source of energy in areas where it was mined easily and plentifully, such as the British Isles and China (Smil, 1994). These three solid fuels that constitute the cooking and heating fuels used by approximately 2.6 billion people today (WHO, 2022). It is estimated that 70% as of households in developing countries use fuels such as wood, dung, and crop residues for cooking and heating (WHO, 2022). According to the WHO household energy database, biomass is most often the primary source of household energy in developing countries. In Asia, many rural areas still depend on biomass, but urban areas are increasingly switching to modern fuels, such as LPG and electricity (Table 1).

The access to modern fuels has been uneven globally. Between 2010 and 2019, the rate of access to cleaner fuels had increased at the pace of 1.0% every year, resulting in approximately 66% of the global population with access to cleaner cooking fuels and technologies. The increase in cleaner technologies and fuels was dominated by five countries: India, Pakistan, China, Brazil, and Indonesia. While excluding these countries, the global access rate to clean fuels and technologies remained unchanged (IEA, 2020). Data regarding fuel usage is updated with new data from national censuses and large-scale household surveys. However, a lack of regular national household energy surveys from various jurisdictions makes it nearly impossible to quantify the state of household fuel use with confidence. Regardless, it is predicted that without substantial policy change, the total number of people lacking access to clean fuels and technologies will remain unchanged by 2030 (IEA, 2020).

Below, in Table 1 highlights, the percentage of households that use solid polluting fuels as a primary fuel, compared to those that use clean fuels and technologies.

Consequently, the HAP attributable disease burden was the highest in sub-Saharan African and South Asia, with 3770.3 and 2068.0 age standardized DALYs per 100,000 population, respectively. Similarly, the age standardized death rate per 100,00 attributed to HAP was the highest in countries such as Nigeria (225.8), Chad (208.3) Sierra Leone (263.2) and India (109.5) and other countries in sub-Saharan Africa and South Asia (WHO, 2018).

Countries	% Polluting Fuels and Technologies			% Clean Fuels and Technologies		
	Rural	Urban	National	Rural	Urban	National
AFRICA						
Benin	99.2	92.6	96.0	0.8	7.4	4.0
Burundi	99.8	99.7	99.8	0.2	0.3	0.2
Cameroon	97.7	61.5	78.1	2.3	38.5	21.9
Eritrea	99.1	80.8	90.7	0.9	19.2	9.3
Ghana	91.7	64.5	77.4	8.3	35.5	22.6
Kenya	95.4	62.1	83.0	4.6	37.9	17
Madagascar	99.6	98.1	99.1	0.4	1.9	0.9
Malawi	99.5	91.5	98.1	0.5	8.5	1.9
Niger	99.9	88.1	97.6	0.1	11.9	2.4
Nigeria	96.3	73.7	87.0	3.7	26.3	13.0
Rwanda	99.8	94.0	98.5	0.2	6.0	1.5
Uganda	99.8	98.8	99.5	0.2	1.2	0.5
Zambia	97.8	68.0	84.3	2.2	32.0	15.7
Zimbabwe	94.1	20.9	70.0	5.9	79.1	30.0
LATIN AR.						
Bolivia	42.6	1.0	4.5	57.4	99.0	85.5
Brazil	20.6	1.3	4.1	79.4	98.7	95.9
Chile	0.0	0.0	0.0	100.0	100.0	100.0
Colombia	32.9	0.9	5.7	67.1	99.1	94.3
Costa Rica	12.8	1.7	4.5	87.2	98.3	95.5
El Salvador	26.0	4.2	10.9	74.1	95.8	89.1
Mexico	42.8	8.5	15.2	57.2	91.5	84.8
Paraguay	60.0	14.4	31.9	40.0	85.6	68.2
Uruguay	0.0	0.0	0.0	100.0	100.0	100.0
Haiti	98.8	92.7	95.7	1.2	7.3	4.3
Nicaragua	91.1	16.7	44.6	8.9	83.3	55.4

ASIA						
India	51.8	9.8	35.8	48.2	90.2	64.2
Nepal	83.9	35.3	69.0	16.2	64.7	31.0
Pakistan	73.8	12.4	50.9	26.2	87.6	49.1
Cambodia	79.9	30.3	68.8	20.1	69.7	31.2
Indonesia	28.1	7.9	17.6	71.9	92.1	82.4
P.N. Guinea	95.6	62.5	90.7	4.4	37.5	9.3
Yemen	57.9	6.9	39.1	42.1	93.1	60.9

Table 2.1: Household distribution of primary fuel choice (WHO, 2022)

1.4 Determinants of the use of solid fuels

1.4.1 Perceptions of Solid-Fuel Use

Most of the exposure, and subsequent disease burden associated with solid fuel use is seen in Low- and Middle-Income Country (LMIC) settings (Stanaway et al., 2018). The use of solid fuels is also strongly associated with the conditions of poverty (Bonjour et al., 2013). Often sited is the ‘energy ladder’, which idealizes a progression from using solid fuels to cleaner fuels, such as electricity and LPG with the acquisition of wealth (Holdren et al., 2000). As such, numerous intervention-based studies have attempted to shift people up the rungs of the energy ladder (Figure 1.1) by adopting cleaner fuels or efficient cook-stoves that burn solid fuels but aim to reduce HAP. However, while income plays a role in the use of solid fuels, complex socio- cultural factors underpin the continued usage of solid fuels. These cultural, behavioral, and historical factors have not been the focus of policy and research. Therefore, while 80 million improved cookstove devices have been distributed since 2010, they have not been used in a sustained manner (Barnes et al., 2005) ‘Fuel stacking’, for instance, is a phenomenon where households continue to use a mix of energy solutions despite having access to clean fuels. A large 2020 scoping review by McCarron et al. studied the users' perceptions of household solid fuel use in LMIC. These findings are broadly grouped into the following categories, and make a non-exhaustive list of factors that contribute to the continued use of solid fuels (McCarron et al., 2020):

Health: Several studies noted that participants either did not recognize the connection between the household solid fuel combustion and their health symptoms or did not perceive smoke or ash to be harmful (Akintan et al., 2018; Cundale et al., 2017; Hollada et al., 2017). In fact, smoke was perceived to be positive, as it protected household members from insects, rodents, and thus these vector-borne diseases (Rehfuess et al., 2014). Similarly, LPG and other clean fuels were highlighted not to have the benefits of other smoke producing fuels, such as insect control (Debbi et al., 2014).

In some studies, participants were noted to be less concerned, or seemingly unaware of the benefits provided by clean, modern fuels and/or cookstoves. Indeed, they may not have an association between their use of solid fuels/stove and any respiratory symptoms (Akintan et al., 2018; Debbi et al., 2014; Hollada et al., 2017).

Family, traditions, and community life: Family and community play an important role in shaping the cultural norms and beliefs pertaining to the use of solid fuels. In many communities, the use of solid fuels is part of a long-standing tradition that is passed down through generations. Therefore, there is an understandable resistance to change (Malakar et al., 2018) . These traditions seemingly impart a reassurance that food cooked with solid fuels had higher nutritional content and even tasted better (Asante et al., 2018; Malakar et al., 2018). Moreover, solid fuels are used for household needs, such as space heating,

heating bathing water, lighting, and cooking. Community-based traditions and practices such as wood-gathering can lead to a sense of belonging and dissuade households from individually adopting cleaner solutions (Malakar et al., 2018; Sunikka-Blank et al., 2019). Therefore, the uptake of solutions such as improved cook-stoves, and cleaner fuels must be done by community leaders, and subsequently communities collectively. The isolated uptake of novel technologies and cleaner fuels has shown to be divisive (Debbi et al., 2014; McCarron et al., 2020).

Home, space, place, and roles: From the included articles, it was clear that the decision-making of the choice of fuel was largely the role of the man in the household. Although, its usage for cooking and heating was largely that of the woman (Debbi et al., 2014; Malakar et al., 2018). While the use of more efficient fuels for cooking saved time, effort, and was clean, the husbands were not always convinced that cleaner fuels were a better option. Therefore, any intervention for improved cook stoves or cleaner fuels would need to target the appropriate audiences in the household. Moreover, other pressing priorities, such as safety from thievery (and thus closed windows), and the prevention of malaria were seen as more important to people than HAP.

1.4.2 Availability and Affordability

The high cost of cleaner fuels and technologies poses a barrier to their uptake and necessitates policy and practices to encourage widespread adoption. Even in communities where cleaner solutions are acceptable, the cost can be a barrier to uptake, especially in lower-income households. In contrast, biomass fuels tend to be more readily available, as collected or produced by the user.

The pricing of modern, clean fuels is a factor that leads to the continued use of solid fuels. Household surveys in ten developing countries, namely Guatemala, India, Indonesia, Kenya, Pakistan, and Sri Lanka find increased uptake of clean fuels with increasing educational attainment and decreasing price of modern fuels (Kojima et al., 2011). The issue of the poverty and HAP is discussed in more detail in section *1.5.2*.

1.5 HAP and Sustainable Development Goals

In 2015, all the UN member states adopted the 2030 Agenda for Sustainable Development. At its heart were the 17 SDGs, that draw attention to a broad set of concerns, from rising levels of inequality, climate change, and decent work to agricultural subsidies, social protection, and responsive and inclusive decision-making at all levels. This set of all-encompassing goals result from the inclusive engagement of an inter-governmental Open Working Group convened by the UN. The process of negotiations included full UN membership. A wide range of experts and stakeholders were mobilized to provide input, including global civil society organizations such as women's rights groups, labour organizations et cetera. This process paid particular attention to the voices of the poorest and most vulnerable.

These SDGs were embarked upon as an agenda of unprecedented importance. Their development and implementation consider different national realities, capacities and levels of development while respecting national priorities and policies. These goals were chosen to broaden and build upon the Millennial Developmental Goals (MDGs), which had expired in 2015. In contrast to the SDGs, the MDGs were seen as targets for mainly the poorer countries, to which the richer ones added their solidarity and assistance through finances and technology. They were seen to be defined in a top-down manner, with narrow aspirations. The progress on the MDGs has been uneven, particularly in Africa, landlocked developing countries, least developed states, and small island developing countries. Their achievement remains off-target most pertain to the maternal, newborn child, and reproductive health.

Although what constitutes 'sustainable development' varies from country to country, it generally comprises a 'triple-bottom-line' approach to human well-being: economic development, environmental sustainability, and social inclusion. Thus, the SDGs recognize that ending poverty and other inequalities is inter-linked with other strategies that improve health and education, and spur economic growth. This is reflected in the 169 integrated and indivisible targets associated with the 17 SDGs. Furthermore, the SDGs pose goals and challenges to all countries – not just what the rich could do for the poor, but rather what all countries could do together for the well-being of the generation and those to come.

SDG 7 – is to "Ensure access to affordable, reliable, sustainable and modern energy for all". This aims to, by 2030: ensure universal access to affordable, reliable, and modern energy services (target 7.1), increase the share of renewable energy in the global energy mix (target 7.2), double the global rate of improvement in energy efficiency (target 7.3), enhance international cooperation to facilitate access to clean energy research and technology and promote investment in energy infrastructure and clean energy technology (target 7.a), and expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States, and land-locked developing countries, in accordance with their respective programmes of support (target 7.b).

The issue of household access to clean energy is central to achieving both the Sustainable Developmental Goals as well as the Paris Agreement on Climate Change. Suppose cleaner fuels and technology are used in such a way to reduce poverty, improve access to health, education, reduce inequalities, and create new opportunities. In that case, it can be said that this energy has social value. Achieving SDG 7 will catalyze action to combat climate change and synergistically attain the other SDGs on gender equality, poverty eradication, health, education, and innovation (among others). Below summarized are the inter-linked challenges that HAP poses and the opportunities that arise from addressing SDG 7.

1.5.1 Gendered impact of HAP:

The gender dynamics of household energy use vary from place to place, but they tend to be driven by deep-seated cultural norms and economic factors. Importantly, the relative power of women and men in household decision making is a crucial factor in the adoption and sustained use of clean fuels and technologies. In most cultures, men have more control over domestic budgets and the choice of household fuels and stoves. On the other hand, women are the primary gatherers and users of household energy. Being exposed to several periods of intense cooking smoke exposure per day, women are among those who benefit the most from the use of cleaner fuels and technologies. Unsurprisingly, that households headed by women generally opt for modern fuels more than those led by men.

Across the world, women spend a greater proportion of their time on household work than men - almost seven times as much in India, for instance. Surveys show that women in rural Indian households spend about 1-2 hours per day collecting firewood, and about 3 hours per day on cooking (Laxmi et al., 2003; World Bank, 2004). The tasks of collecting, and cooking with solid fuels deprive women and girls of the time to pursue an education, earn an income and engage in other opportunities for development. A transition to cleaner fuels would not only cut down the time taken in fuel collection, but also provide opportunities for education through electrification. Benefits would include time for business, education attainment, general welfare, and health. The indirect impacts of energy collection (direct impacts being the narrowly defined "health" impacts) have received much lesser attention from researchers and policymakers than the impacts of energy use. Formal economic indicators fail to consider the value of domestic work performed by women in the developing world. Without these important indictors, it becomes difficult for advocates, and for governments and organizations to develop effective policies and programmes

Since women are exposed to the highest concentration of HAP, they are particularly vulnerable to the disease caused by HAP, such as asthma, pneumonia, COPD, and acute lower respiratory tract infections (Gordon et al., 2014; Smith et al., 2014). For instance, the likelihood of acute respiratory infection and acute lower respiratory traction infection in women exposed to HAP smoke indoors is twice as high as that in men (Ezzati & Kammen, 2001). The odds of developing COPD due to biomass smoke exposure are 20% higher for women, than it is for men (Smith et al., 2014). There are also indirect health risks of women and children gathering fuels, such as trauma, assault, and injury. Therefore, interventions should target high-risk groups such as women and children, to reduce exposure to HAP.

1.5.2 Poverty and HAP:

Though poverty is strictly defined in terms of monetary value, it is a multi-dimensional concept, that is associated with non-monetary factors. These factors include but are not limited to - access to basic utilities, political participation, and access to health facilities et cetera. As a result, the energy provided to one community can often impose costs, burdens, and risks on others.

The energy ladder model of fuel use predicts that as households experience an increase in income, they will switch from traditional, dirtier fuels such as solid fuels to modern, cleaner fuels such as natural gas and electricity (Holdren et al., 2000). The converse also seems to hold; It is well documented that improving access to affordable and reliable forms of clean energy is essential in reducing poverty and promoting economic development (Barnes et al., 2011; Modi et al., 2005). The economic benefits of a transition to cleaner fuel include time saved collecting fuels, fuel cost savings, healthcare expenditure, and other benefits, such as social status, aesthetics et cetera. For instance, studied households in Nepal, Sudan and Kenya and reported economic benefits from cooking stove interventions, mainly due to fuel and cooking time savings (Malla et al., 2011). Similar findings are reported across studies in different settings, such as Kampala, Uganda (Habermehl, 2017). However, other studies report no benefits of a transition to clean fuels on economic indicators (Aklin et al., 2017). Arguably, the time saved and wages earned from the lack of fuel collection in a transition to clean fuels would only manifest in a setting with enterprises and markets for rural business (García-Frapolli et al., 2010, . Therefore, clean energy may be necessary but not sufficient for economic development. For clear energy to be of social value, they require both the technical systems that deliver access to energy and enterprise to expand energy access and economic development.

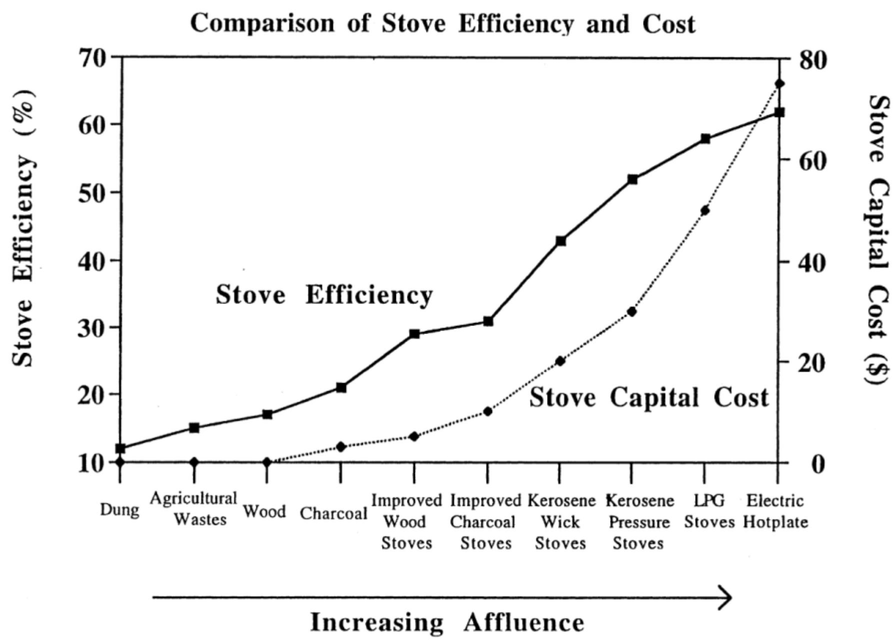

Figure 1.1 Energy Ladder (Holdren et al., 2000)

Although there have been significant efforts to electrify and provide cleaner energy, ‘fuel-stacking’ remains commonplace. This is when households that have access to modern energy sources continue using biomass, for cooking, for instance. This is after the adoption of electricity and/or LPG, which is used for other household purposes. Therefore, contrary to the energy ladder theory, despite economic development, HAP from using of solid fuels can persist. Another 2008 study noted that in wealthier, urban households, is accompanied by a diversification of fuel choice, rather than a complete transition (Mekonnen & Köhlin, 2009). This would negate any of the reduction in health risks that come from the adoption of clean fuels and technologies. For households, and resultantly, communities, to reduce HAP – they need the will to change behaviour. This comes from increased affordability, access to clean fuels, and an appreciation of its benefits. There is a need for more qualitative research, to understand better which households use interventions in the way they do, including fuel stacking and other aspects of adoption.

The energy sector has historically been an offender of human rights and corruption. Beyond the adoption of solid fuels, the energy-poverty nexus manifests in various other pathways. For instance, coal and petro-chemical power plants (often emitting toxic emissions) and mining industries that serve urban communities are often set in rural areas and areas of low socioeconomic status. These have created health risks for communities living near these industries. Moreover, various factors can drive the price of energy beyond the means of the poor, who are also the most vulnerable. These groups of people can also lack political participation, access to programs and policies, and healthcare, only amplifying the effects of dirty energy on their health and well-being.

1.5.3 Education and HAP

Households that rely on polluting, solid cooking fuels generally have a higher prevalence of children aged between 5 and 14 who are engaged in collecting fuel and water. Although this prevalence varies from country to country, it is noteworthy that in some countries, this prevalence is as high as 80% of children aged 5-14 years. Girls in Benin spend half the time collecting fuel wood and water in households that use clean fuels, compared to those that use solid, polluting fuels. School going children derive a direct benefit from electrification from the use of clean fuels and technologies. This is seen in educational outcomes, such as school enrollment, and study time at home (Aguirre, 2017; Khandker et al., 2009). For instance., an improvement in educational attainment due to accessible lighting, and a reduction in birth rates, as evidenced in rural Bhutan and the Ivory coast (Peters & Vance, 2011)

Moreover, education is also a factor in determining household fuel choice. For instance, a study found that women's educational attainment is considered cleaner in rural Kenya (Pundo & Fraser, 2006). Similar findings were reported from eight developing countries (Heltberg, 2003) and India (Pandey & Chaubal, 2011).

1.6 Objective of Thesis

This thesis document consists of two comprehensive systematic reviews and meta-analysis that evaluates the most up-to-date evidence on the adverse health outcomes associated with HAP and calculates the pooled meta-estimates for the asthma and ALRI outcomes. The research questions that these studies seek to answer, are:

1) What is the pooled risk estimate of asthma, among children exposed to HAP compared to those not exposed or exposed to HAP from improved cookstoves?

2) What is the pooled risk estimate of ALRI among children exposed to HAP compared to those that are not exposed or exposed to HAP from improved cookstoves?

3) Does early life exposure to HAP affect lung function in children?

There is an urgency for evidence-based policy making and action to reduce the substantial burden of disease associated with HAP, particularly in LMIC. Additionally, this thesis situates

CHAPTER 2: METHODOLGY

2.1 Introduction

As mentioned in Section 1.6, this thesis project aims to summarize the up-to-date literature on the effects of household air pollution on children's respiratory health. To our knowledge, this has been the first systematic review examining the effects of HAP on childhood lung function. Additionally, the evidence on the effects of HAP on asthma and ALRI appears to be mixed, due to diverse study participants, and the manner of use of fuel types (Guercio et al., 2021). Moreover, there has been no systematic review examining the effects of HAP, specifically on childhood asthma and ALRI since 2008. Therefore, it was necessary to conduct a systematic review with evidence from recent studies. Systematic reviews serve their purpose when they are the most up to date. Intervention changes may occur over time (e.g., modern fuels and cooking technologies). Without considering these changes, systematic reviews may lose their validity (Moher et al., 2008).

The timely provision of evidence is especially important in the field of global health, as implementing agencies, governments, donors et cetera require up-to-date evidence to inform policy development. As elaborated on in section 1.3, there is an urgent need for a change in policy, to reduce the total number of people lacking access to clean fuels and technologies by 2030 (IEA, 2020).

A narrative synthesis method has been employed in the systematic review examining the effects of HAP on childhood lung function due to the high degree of heterogeneity in outcome measures, and participant characteristics. A meta-analysis was conducted in the systematic review examining the effects of HAP on asthma and ALRI. This difference in evidence synthesis led to the differentiation between the two papers.

2.2 Research Protocol

2.2.1 Methods and Analysis

The protocol for this systematic review was registered on PROSPERO (CRD42021236671) and is available in full on https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42021236671. This protocol is based on the Preferred Reporting Items for Systematic Review and Meta-Analysis Protocols (PRISMA-P) Statement (see figure 2.1)

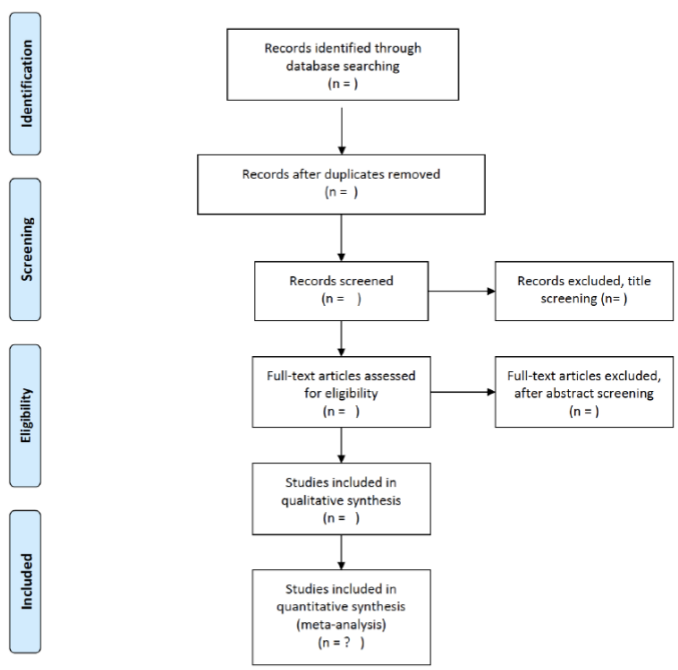

Figure 2.1: Process of study selection as per PRISMA protocol

2.2.2 Eligibility Criteria

Population:

We will include individuals, less than or equal to 18 years of age, with a diagnosis of asthma, or ALRI, or measurement of lung function. Participants over the age of 18 are ineligible for inclusion. Studies conducted exclusively on animals or human adults (those greater than the age of 18 are excluded).

Exposure:

Exposure to HAP, particulate matter from domestic solid fuel combustion for cooking and/or heating will be included as exposures for these reviews. The exposure may be further categorized by fuel type, which can include biomass, coal, charcoal, animal dung, wood or agricultural residue et cetera.

Comparator:

The non-exposure to HAP, or the exposure to cleaner fuels and/or technologies for cooking and heating will be included, as the comparator for these reviews.

Exclusion:

Studies investigating sources of air pollution that are exclusive of an outdoor or ambient source, exposure to allergens, tobacco smoke, or those that do not distinguish between outdoor, and HAP are excluded from this review.

Outcome(s):

Physician-diagnosed or self-reported asthma, a physician-diagnosed acute lower respiratory infection, and standardized measures of lung function indices were the outcomes of interest in the review.

Measure(s) of Effect:

The principal measure of effect will be the relative risk of outcome measured between the binomial exposure variables of exposure (i.e., the group exposed to HAP will be considered the highest category; the comparator group will be considered the lowest category or treatment vs. control) for the dichotomous outcomes of asthma and ALRI incidence; and the mean difference (MD) or standardized mean difference (SMD) as appropriate, between exposure groups (e.g. highest vs. lowest; or treatment vs. control) between continuous outcomes, such as the measures of lung function index.

Study Design(s):

Observational studies including cohort, cross-sectional and case control studies will be included in this review. Interventional studies including randomized controlled trials will also be included. Gray literature, case studies/series, narrative reviews, and non-peer reviewed publications such as editorials, commentaries, newspaper articles and other forms of popular media will be excluded. All papers written in languages other than English will be excluded from the review due to limited resources for translation. There will be no restrictions on geographic location or study setting.

Literature Search:

A Senior Health Sciences Librarian with proficiency in systematic review methodology and search strategy development has assisted in developing the search strategy. The following databases will be searched to identify studies: Ovid EMBASE, MEDLINE, Global Health, Web of Science, and Scopus. The bibliographic reference lists from studies selected for inclusion will be manually checked for potential inclusion in the meta-analysis.

Studies with an abstract available in English will be considered, other language restrictions will not be imposed. The search will be limited to studies published from 1980 to the date of search (February 2021). This search will be updated three months prior to the submission of the study manuscript(s).

Data Extraction:

The screening procedure has been conducted using the PRISMA guidelines. A preliminary version of the PRISMA diagram for the reporting of this review is presented in figure 2.1. Duplicate references were be removed using COVIDENCE, a web-based systematic review software. Two reviewers assessed the titles and abstracts of the studies identified electronically and manually for eligibility independently and in duplicate. Two reviewers assessed the full text of eligible studies for inclusion or exclusion independently. Data from included studies were extracted independently and duplicated onto a piloted, standardized data collection form. Data collected included study design, years of follow-up, country, participant characteristics, fuel exposure type and comparator, outcomes, ascertainment of outcomes, and data required for risk of bias assessment. The reviewers meet after the title and abstract screening and full-text review to assess agreement and will resolve disagreements by discussion. On the occasion of a conflict that persisted, a third independent reviewer was consulted to reach a consensus.

Data Synthesis:

Meta-Analysis was performed using the Stata software (*STATA Statistical Software*, n.d.) to determine the overall pooled effect estimates. Pooled RR was determined for the dichotomous outcomes of asthma and ALRI incidence, and the mean difference in risk

(DR) will be calculated, if feasible for continuous outcomes of lung function indices. The inverse-variance method was used as studies with smaller variance are assigned a greater weight in the estimate calculation. Based on the similarity of the study populations and outcomes that we pool, it was decided to use random effects models as the studies included were of different study designs and probably higher heterogeneities. Statistical heterogeneity was calculated using the I^2 statistic. Funnel plots, Egger and Begg's test. Meta-regression was done to identify the sources of heterogeneity.

Risk of Bias (ROB) assessments:

The Risk of Bias (ROB) Assessment will be conducted via the Newcastle Ottawa scale (NOS) and independently by two investigators (S.A and S.G), and conflicts will be resolved by a third (O.K). A 'star' system is used in the NOS, in which studies are judged on three broad perspectives: the selection of study groups, the comparability of the groups, and the ascertainment of either the exposure or the outcome of interest. The content validity and inter-rater reliability of the NOS have already been established. The major confounders in the associations studied in this review include age, sex, and exposure to tobacco smoke. Other potential confounding variables include - seasonality, weather, influenza epidemics, population characteristics and lifestyle factors.

Ethics and Dissemination:

We were not required to undergo a formal ethics board review by McMaster University, as this thesis project was a systematic review that involved no human participants. We aim to publish this review in a high-impact journal with open access to ensure early and broad access to findings. The systematic review and meta-analysis results will be presented at relevant conferences. The feedback received will be used to improve the effectiveness of the message.

2.12 Discussion

This systematic review will summarize the effects of HAP on childhood lung function and the prevalence and/or incidence of childhood asthma and acute lower respiratory tract infection. The primary supervisor of this study and respirologist, Dr. Om Kurmi, will assist in the evidence synthesis and the interpretation of the results. Our synthesis will be a resource for policymakers seeking to assess the evidence on the effects of HAP. Our extensive systematic search of five databases will ensure we capture all relevant studies.

CHAPTER 3: THE EFFECTS OF HAP ON LUNG FUNCTION DURING CHILDHOOD

Complete citation:

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Author Contributions

Conceptualization, S.S.A. and O.P.K.; methodology, O.P.K.; validation, S.S.A., S.G. and O.P.K.; formal analysis, S.S.A.; writing—original draft preparation, S.S.A.; writing—review and editing, O.P.K., I.S., S.K.T. and C.E.B.; supervision, O.P.K.; All authors have read and agreed to the published version of the manuscript.

3.1 Abstract

The World Health Organization (WHO) estimates that around 2.6 billion people today are exposed to smoke from the household combustion of solid fuels. While the household use of solid fuels has decreased over the last few decades, it remains a leading modifiable risk factor for the global burden of disease. This systematic review analyzed the impact of Household Air Pollution (HAP) on lung function in children (under 18 years of age), as this is the time of accelerated growth rate until full skeletal maturity. Data from 11 published studies demonstrated that exposure to smoke from solid fuel was associated with

a lower growth rate of several lung function indices (FVC, FEV_1, $FEF_{25–75}$) in children. However, there was no observed association between HAP and the FEV_1/FVC ratio over time. Although the evidence suggests an inverse association between high exposure to HAP and lung function indices, there is a lack of longitudinal data describing this association. Therefore, precaution is needed to reduce the smoke exposure from solid fuel burning.

3.2 Introduction

The World Health Organization (WHO) estimates that around 2.6 billion people or about 40% of the world's population are exposed to smoke from the burning of solid fuel (coal, wood, animal dung, or crop waste) burning for cooking or heating purposes[1]. The combustion of these solid fuels is inefficient and produces high airborne pollutants, including soot particles that can penetrate the lungs[2]. The incomplete combustion or inefficient combustion of these fuels emit smoke containing high levels of pollutants such as carbon monoxide, oxides of nitrogen, and sulphur, which are detrimental to human health. This has been linked to impaired lung function and respiratory morbidities such as asthma and lower respiratory tract infections[2.3]. Despite substantial reduction in the use of solid fuels globally, exposure to Household Air Pollution (HAP) from using these fuels for cooking remains a leading modifiable risk factor for global disease burden[4]. Among environmental risk factors, the contribution of HAP to disease burden is second only to ambient particulate matter pollution. In 2019, 91.5 million global disability-adjusted life years (DALYs) were attributable to HAP, a decline of more than 50% from 1990; however, the absolute number exposed to HAP has remained the same over the last four decades[5]. In total, 2.31 million global deaths were attributable to HAP and accounted for 4% of all deaths in 2019. The HAP-attributable burden remains the highest in sub-Saharan Africa and South Asia, with 3770.3 and 2068.0 age-standardized DALYs per 100,000 population, respectively[4,5]. Additionally, the poorest countries from low-income and middle-income countries (LMICs) are associated with the highest prevalence of HAP related complications.

People, particularly women and children in LMICs, spend a considerable amount of their time indoors, with poor ventilation systems making them more susceptible to HAP. HAP accounts for two million yearly deaths from Acute Respiratory Infections (ARI) in children[1]. Children may be especially vulnerable to indoor pollutants because of their immature immune systems and at a time period of rapid growth and development. Infants and children also inhale a larger dose of air per unit of body mass at a given activity level than adults in the same environment, hence, inhaling disproportionately high concentrations of air pollutants[2].

Timely and accurate information is urgently needed to facilitate the development of effective global health strategies to prevent further damage to the lung from HAP. There have been a limited number of studies investigating the relationship between exposure to HAP and lung function impairment in children. Our primary aim was to systematically summarize, synthesize, and analyze the extent of HAP-related lung impairment in a pediatric population from peer-reviewed publications.

3.3 Materials and Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. An a priori protocol was published in PROSPERO, ID: CRD42021236671[6].

The following databases were systematically searched from 1980 to 21 February 2021, to identify studies: Ovid EMBASE, MEDLINE, the Global Health, Web of Science, and Scopus. Variations of the terms "air pollution", "lung function", and "children" were used with the "AND" Boolean operator. A complete list of keywords and search strategies is attached in Appendix A, in Tables 1A-4A. Following the predetermined inclusion criteria, titles/abstracts and full texts of retrieved articles were independently screened by two reviewers (S.A. and S.G.). Any arising conflicts were resolved by a third reviewer (O.K.). The bibliographic reference lists from studies selected for inclusion were manually checked for potential inclusion by a reviewer (S.A).

Original articles written in English were included if they involved human participants less than or equal to 18 years of age, recorded exposure to HAP, and measured lung function, with a comparator group of exposure. Participants exposed to HAP from occupational exposures were ineligible for inclusion. Studies investigating sources of air pollution that were exclusively outdoor/ambient, non-fuel combustion, tobacco smoke exposure, allergens, or those that did not distinguish between outdoor and household air pollution were excluded.

Randomized controlled trials, cohort studies, case-control studies, cross-over studies, and cross-sectional studies were included in this review. Grey literature and case reports/series were excluded from this review. Additionally, conference abstracts, posters and studies with irretrievable full texts were excluded. Lastly, studies that lacked a comparator group were not considered for inclusion.

Two reviewers (S.A. and S.G.) independently extracted data from each included study. Data collected included study design, country, participant characteristics, fuel exposure type and comparator, outcomes, ascertainment of outcomes, and data required for risk of bias assessment. HAP was defined as indoor air pollution from domestic solid-fuel combustion for cooking and/or heating (wood, charcoal, kerosene, animal dung, crop residues, pellets, coke, and coal). Pulmonary function, measured by volumes or flow rates during spirometry, was recorded in those exposed to HAP. Outcomes included metrics for pulmonary function, which were Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 s (FEV_1)**,** the ratio of FVC and FEV_1 (FVC/FEV_1), Forced mid-expiratory flow ($FEF_{25–75}$), and Peak Expiratory Flow Rate (PEFR). The comparator group was defined as children exposed to relatively cleaner household fuels (such as Liquified Petroleum Gas (LPG), natural gas, or electricity) or a non-exposed comparator group.

The Risk of Bias (ROB) Assessment was conducted using the Newcastle Ottawa scale (NOS) by two independent investigators (S.A) and (S.G). Cross-sectional studies' ROB was assessed using a modified Newcastle-Ottawa scale. The 'star system' used in the NOS judged a study based on three broad perspectives: the selection of the groups of study (maximum of 4 stars); the ascertainment of the exposure or outcome of a study in case-control or cohort studies, respectively (maximum of 3 stars), and the comparability between the groups of study (maximum of 2 stars). A study could therefore have a maximum of 9 stars. Conflicts were resolved by a third reviewer (O.K). The ROB assessment for individual studies can be found in Appendix B, Tables 4B and 5B for cohort and cross-sectional studies, respectively.

We did not conduct a meta-analysis due to high heterogeneity in study design and between the subjects in the included studies in age, geographic location, race, and factors such as the outcome assessment. Instead, the effect estimates were summarized by grouping according to lung function outcome. The range, distribution, and direction of HAP on each specified measure of lung function, FVC, /FEV_1, FEV_1/FVC, $FEF_{25–75}$, and PEF was organized. The metrics used for synthesis and interpretation included measures of effect such as percent predicted values, mean values, and mean differences.

3.4 Results

3.4.1. Study Characteristics

The initial search yielded 345 results. After removing duplicates, 232 titles and abstracts were screened, following which a further 195 articles were excluded as they did not meet the eligibility criteria. Of the remaining 37 articles, which moved on to the full-text screening stage, 11 were included in the systematic review and used for the data extraction and analysis. The PRISMA flow diagram in Figure 3.1 below illustrates the search results. In total, three cohort studies and eight cross-sectional studies were included. The studies included were published between the years 1990 and 2016. Three studies were conducted in low-income countries, six were conducted in upper-middle-income countries, and one was conducted in a high-income country. Specifically, the included studies took place in Brazil[7], China[8], Ecuador[9], Guatemala[10], Turkey[11], Honduras[12], India[13], Jordan[14], , Malaysia[15], Nigeria[16], and Poland[17]. All included studies had a score of ≥6 and were considered high quality based on the Newcastle-Ottawa Scale. A summary of the included studies can be found in Appendix B, Table 1B.

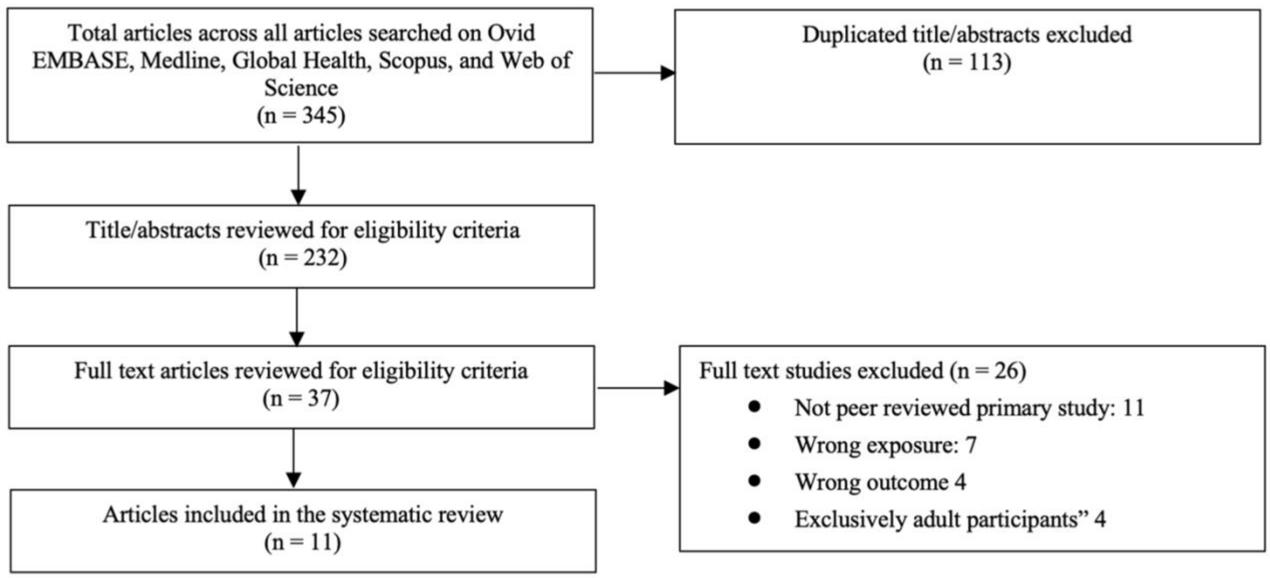

Figure 3.1: Study selection as per PRSIMA protocol for studies examining HAP and lung functionl[6]

3.4.2 Population Characteristics

In total, data were collected from eleven studies consisting of a total of 10,590 participants. The ages of participants ranged from 5 to 17 years. Of the studies that provided the sex distribution of participants, the percentage of males ranged from 45.1% to 57.9%. The exposures included the use of fuels for household heating and/or cooking such as coal[8,17]. Wood[14,15], biomass[7,9,10,12,13,16,18] and natural gas or electricity[9,13].

3.4.3. Study Outcomes

All eleven of the included studies provided spirometry measurements of lung function. FEV_1, FVC, FEV_1/FVC, $FEF_{25–75}$, and PEF were the frequently reported lung function outcomes.

<u>FEV_1</u>:

The use of coal was associated with a 16.5 mL/year (33% of average annual growth rate of FEV_1, $p < 0.001$) lower annual growth of FEV_1 when compared to those with no use of coal in a prospective cohort study of 3273 children aged 6–13 years[8]. Similarly, a prospective cohort study of 506 Guatemalan children aged 5–8, exposed to biomass combustion reported a decrease of 44 mL/year ($p = 0.07$) in annual FEV_1 growth among those with a chimney-stove (named *Plancha*) intervention at 18 months, compared to those with the chimney-stove installation at birth[10]. The effects of postnatal exposure to HAP on preadolescent lung function were also examined by a retrospective cohort study from Poland that found that increased exposure to indoor pollution in the winter during the first six months of life was inversely related to FEV_1 ($\beta = -0.13$, $p = 0.03$)[17], when measured at 9 years of age, for 1036 children. A cross-sectional study of Ecuadorian children aged 7–15 years reported that those living in homes with the exclusive use of biomass for cooking were associated with lower FEV_1 than those using LPG exclusively. ($\beta = -0.39$, $p < 0.01$)[9]. Similarly, the use of biomass for cooking was associated with a lower mean FEV_1 of 80 mL among Malaysian children aged 7–15[15]. In India, a study reported children living in households that used biomass for cooking had a mean FEV_1 of 0.6 L/s ($p = 0.005$) lower than those using LPG[13].

<u>FVC:</u>

A prospective cohort study of 3273 children aged 6–13 years from China reported that the lifetime use of coal as household heating fuel was associated with a mean decrease of 20.5 ml/year in FVC growth over four years compared with those who had no use of coal as a household heating fuel (39% of average annual growth rate of FVC, $p < 0.001$)[8]. Similarly, a prospective cohort study of 506 children from Guatemala aged 5–8 years demonstrated a large but statistically nonsignificant decrease in FVC growth of 39 mL/year ($p = 0.16$) among those with biomass combustion and chimney-stove intervention at 18 months, compared with those with stove installation at birth[10]. The effects of postnatal exposure to HAP on preadolescent lung function were also examined in a retrospective cohort study from Poland that found that increased exposure to indoor pollution in the winter during the first six months of life was inversely related to FVC ($\beta = -0.15$, $p = 0.01$), measured at age 9[17]. Cross-sectional studies showed similar lower mean FVC values in children exposed to the combustion of solid fuels. A cross-sectional study of children from Ecuador aged 7–15 years reported that those living in homes with the exclusive use of biomass for cooking had lower FVC than those using LPG exclusively. ($\beta = -0.41$, $p < 0.05$)[9]. Similarly, the use of biomass for cooking was associated with a lower mean FVC of 90 mL among children from Malaysia aged 7–15 years[15]. In India, a study reported children living in households that used biomass for cooking had a mean FVC of 1.7 L/s ($p = 0.002$) lower than those using LPG[13]. The studies that reported percent predicted values of FVC showed decreases between 5 and 15% with exposure to biomass combustion[15,18].

<u>FEV_1/FVC:</u>

A prospective cohort study of children aged 6–13 years reported no significant longitudinal changes in FEV_1/FVC ratio were observed in association with coal use or ventilation[8]. Similarly, the other cohort and cross-sectional studies examining the effect of HAP on FEV_1/FVC among children reported no differences between different categories of solid fuel use.

FEF_{25-75}:

A prospective cohort study of 506 children from Guatemala aged 5–8 years reported a lower statistically nonsignificant $FEF_{25–75}$ annual growth rate (−23 mL/min/year, $p = 0.73$) among chimney cookstove installation at 18 months, compared to those with installation at birth [10]. A cross-sectional study of 1905 children from Jordan aged 7–15 years reported that those with lifetime exposure to wood and kerosene stoves had a mean unadjusted $FEF_{25–75}$ of 0.62 L/s ($p < 0.005$) lower than those without lifetime exposure to wood and kerosene stoves[14]. Similarly, a cross-sectional study of 77 children from Ecuador aged 7–15 years reported that those living in homes that the use of biomass primarily for cooking was associated with lower $FEF_{25–75}$ when compared to LPG as well ($\beta = -0.89$, $p < 0.05$)[9].A large cross-sectional study of 1505 children from rural east India aged 5–10 years showed that those living in homes that used biomass cooking fuel exclusively had a lower $FEF_{25–75}$ of 0.77 L/s ($p = 0.012$) than those using LPG[13].

3.5 Discussion

The study results demonstrate that the use of solid fuels may lower the lung volumes and flow rates in children (FVC, FEV_1, $FEF_{25–75}$). There was no observed association between HAP and the FEV_1/FVC ratio over time. This would suggest that HAP mainly brought similar reductions in FEV_1 and FVC. However, the findings are based on a few studies only and would need to be validated from large prospective cohort studies. To the best of our knowledge, this is the first systematic review to examine the association of HAP on lung function in children.

There is a need for more prospective studies to assess the long-term impacts and exposure–response nature of the risk of HAP on lung development and function. There is also a need for further research into the effects of solid fuel combustion on the lung development of children under the age of 5 years. It is known that the first two years of life are vital for the development of the lungs[19]. However, there has been very little research examining the association between solid fuel combustion and lung function at this age to the best of our knowledge. This is because it is hard to assess lung function in children under the age of 5 years, and it is due also to the unavailability of resources including the spirometers in rural areas of LMICs where HAP is predominantly used. However, oscillometry is increasingly being used in pulmonary clinical practice, as well research to assess lung function in such populations (Lundblad et al., 2021). Given the higher risk faced by women and children, the impacts of HAP on sex and gender should be a consideration in future research examining this association.

There is a possibility of residual confounding factors in the association between solid fuel use and lung function. For instance, socioeconomic factors such as income, education, and nutrition could lead to changes in health status, lung growth, and the greater use of solid fuels. In studies that encompass a variety of socioeconomic backgrounds (for instance, studies including rural and urban participants), adjustment for socioeconomic status is necessary. Questionnaire responses to solid fuel use, such as the choice of fuel and frequency of use, can lead to exposure misclassification and bias towards the null. It is also probable that the parents of children with respiratory ailments could have over-reported or under-reported the duration of use of solid fuels. Basic spirometry can be measured by the investigator with relative ease and inexpensive equipment. However, interpretation of spirometry tests can be challenging, as the tests are primarily dependent on participant effort and cooperation. Therefore, prior to interpretation, spirometry results must always be assessed for validity, which may not have been conducted in every study. The context of a spirometry test is important, as these values can vary between height, weight, age, sex, or ethnic background.

The methodological quality of the studies included in the present review was relatively homogenous, as determined by the NOS tool. However, the NOS tool is designed for classic cohort and case-control studies. Properly assessing the quality of environmental cross-sectional studies remains a challenge. To avoid selection bias, two independent reviewers conducted the screening and selection processes. However, some unpublished studies and studies not in English were not included. Therefore, there is a chance of publication bias. However, the included studies were diverse in their geographic area of study.

The scope of the current review was limited to the childhood population. However, diminished lung function in childhood is a strong predictor of subsequent low lung function in adulthood[19,21,22]. This may in turn predispose the affected to develop diseases such as COPD in adulthood[23]. However, this study demonstrates the harmful effects of HAP on lung function in children and demonstrates the need for policy to enact early intervention.

3.6 Conclusion

This systematic review contributes to the evidence of the adverse impact of HAP on lung function in children. The results of this study suggest that the household use of solid fuels such as coal, wood, kerosene, and biomass may significantly lower lung function growth (FVC, FEV_1, and FEF_{25-75}) among children.

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CHAPTER 4: THE EFFECTS OF HAP ON ASTHMA AND ACUTE LOWER RESPIRATORY INFECTION

4.1 Abstract

The World Health Organization (WHO) estimates that around 2.6 billion people today are exposed to smoke from the household combustion of solid fuels. While the household use of solid fuels has decreased over the last few decades, it remains a leading modifiable risk factor for the global burden of disease. Women and children are particularly vulnerable to the effects of HAP, due to their higher exposure from their time spent indoors.

This systematic review and meta-analysis aimed to estimate the impact of HAP exposure on the incidence of asthma and ALRI in children, or those under the age of 18. Peer reviewed articles published in English were identified from searches of the Ovid EMBASE, Medline, Global Health, Web of Science and Scopus databases. Studies that reported an outcome of childhood ALRI or asthma in relation to HAP from the use of solid fuel. Among the 791 articles identified, 229 full texts were reviewed and 110 were included in meta-analyses. Data from 72 published studies demonstrated that exposure to smoke from biomass combustion was associated with an increased risk of incidence of ALRI in children. However, there was no observed association between HAP and the incidence of asthma in children from data from 38 published studies.

The results of this systematic review are consistent with previous research examining the same associations and provides the most up-to-date evidence examining the effect of HAP. ALRI, and their resulting pneumonia are the primary cause of death among children younger than five (WHO, 2022). HAP exposure is responsible for 45% of all pneumonia deaths under the age of 5 (WHO, 2022). Given the relative risk of using solid

fuels, compared to that using clean fuels and technologies, there is an urgency for the uptake of clean fuels and technologies.

4.2 Introduction

The World Health Organization (WHO) estimates that around 2.6 billion people, or a third of the world's population uses solid fuels (coal, wood, animal dung, or crop waste) for cooking and heating (IEA, 2020, n.d.). The combustion of these fuels is inefficient, and releases nitrogen dioxide (NO_2) and particulate matter ($PM_{2.5}$) among other toxic substances into the surrounding environment. In homes that use solid fuels for cooking and heating, on average the levels of particulate matter of less than 2.5 microns (PM2.5) in diameter range from 500 to 1500 µg/m^3 (Bruce et al., 2015). This is high, as the permissible indoor levels of $PM_{2.5}$, according to the WHO range between 10 to 50 µg/m3 in a 24 hour mean value(K.-H. Kim et al., 2015). The air pollution due to the combustion of solid fuels in the indoor environment for the purposes of heating and cooking is referred to as a Household Air Pollution (HAP).

Globally, the exposure to Household Air Pollution (HAP) is among the top ten risk factors for disease, with the highest prevalence observed in the poorest communities in low-income and middle-income countries (LMICs) (Bennitt et al., 2021; WHO, 2022). Thus, the importance of HAP as a public health threat varies drastically by the level of development. The higher cost of cleaner fuels and combustion technologies is a barrier to their accessibility. As a result, the access to cleaner household energy increased at an annual rate of 1.0% percent per year between 2010 and 2019 (WHO, 2022). Most of this increase was seen in the populous countries of China, Brazil, India, Indonesia, and Pakistan (2020).

When excluding these countries, the global access rate to cleaner fuels remained unchanged in the last decade. In sub-Saharan Africa, for instance - since 2015, only 25 million people have gained access to clean cooking in the region (WHO, 2022). The growth in population has outpaced the growth in access to cleaner fuels and technologies, leaving 900 million without access to cleaner cooking (IEA, 2020). More than eighty-five percent of the population remains reliant on inefficient and dangerous cooking systems. Furthermore, the COVID-19 pandemic could reverse the progress made in electrification in some countries. Firstly, increased poverty due to the crisis could lead households to re-uptake fuels such as biomass, charcoal, and kerosene. Secondly, government programmes in the energy access area have been hindered due to shifting government priorities (IEA, 2020).

Each year, approximately 3.8 million people die prematurely from illness attributable to HAP (Bennitt et al., 2021). In developing countries, HAP is responsible for approximately 10% of all mortality, while globally this figure is approximately 7.7% (Bennitt et al., 2021; WHO, 2022). According to the WHO global data as of 2022, is considerable evidence linking HAP to chronic obstructive pulmonary disease, ischemic heart disease, stroke, asthma, and lung cancer (WHO, 2022). Women and children in low- and middle-income countries (LMICs) spend a lot of their time indoors, and furthermore, the exposure to HAP is closely associated with the risks of developing respiratory infections such as pneumonia, tuberculosis, and conditions such as aggravated asthma. Among children less than 5 years of age, exposure to HAP doubles the risk of pneumonia and is responsible for 45% of all pneumonia caused deaths (WHO, 2022).

Given the relative magnitude of the burden of HAP, there is a need for timely and accurate information on the impact of HAP. A comprehensive systematic review and meta-analysis was conducted to review the most up-to-date evidence on the specific adverse health outcomes of asthma and acute lower respiratory tract infection associated with HAP in a pediatric population.

4.3 Methods

This study was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. A PRISMA checklist is enclosed as Table S1 in the Supplementary files. An a-priori protocol was published in PROSPERO, ID: CRD4202123667(Aithal et al., 2021).

4.3.1. Search Strategy and Criteria

The following databases were systematically searched from 1980 to 21 February 2021, to identify studies: Ovid EMBASE, Medline, the Global Health, Web of Science and Scopus. Variations of the terms “air pollution”, “asthma”, “acute lower respiratory tract infection” and “children” were combined with the AND Boolean operator. A complete list of keywords and search strategies is attached as Appendix Tables 1A-5A. Furthermore, studies were also identified through searches of bibliographies and references.

Original articles written in English that involved human participants less than or equal to 18 years of age were included, if they had a recorded exposure to HAP, and reported an outcome of asthma, acute lower respiratory tract infection, or a respiratory symptom (cough, and or wheeze). The use of cleaner fuels and/or technologies such as natural gas, electricity and cleaner burning, efficient stoves were considered alternative to polluting fuels. Studies comparing the risk of outcome in those exposed to polluting fuels (coal, charcoal, wood, biomass, kerosene, or agricultural residue) to that from the exposure to cleaner fuels and/or technologies (natural gas, electricity and cleaner burning, efficient stoves) were included.

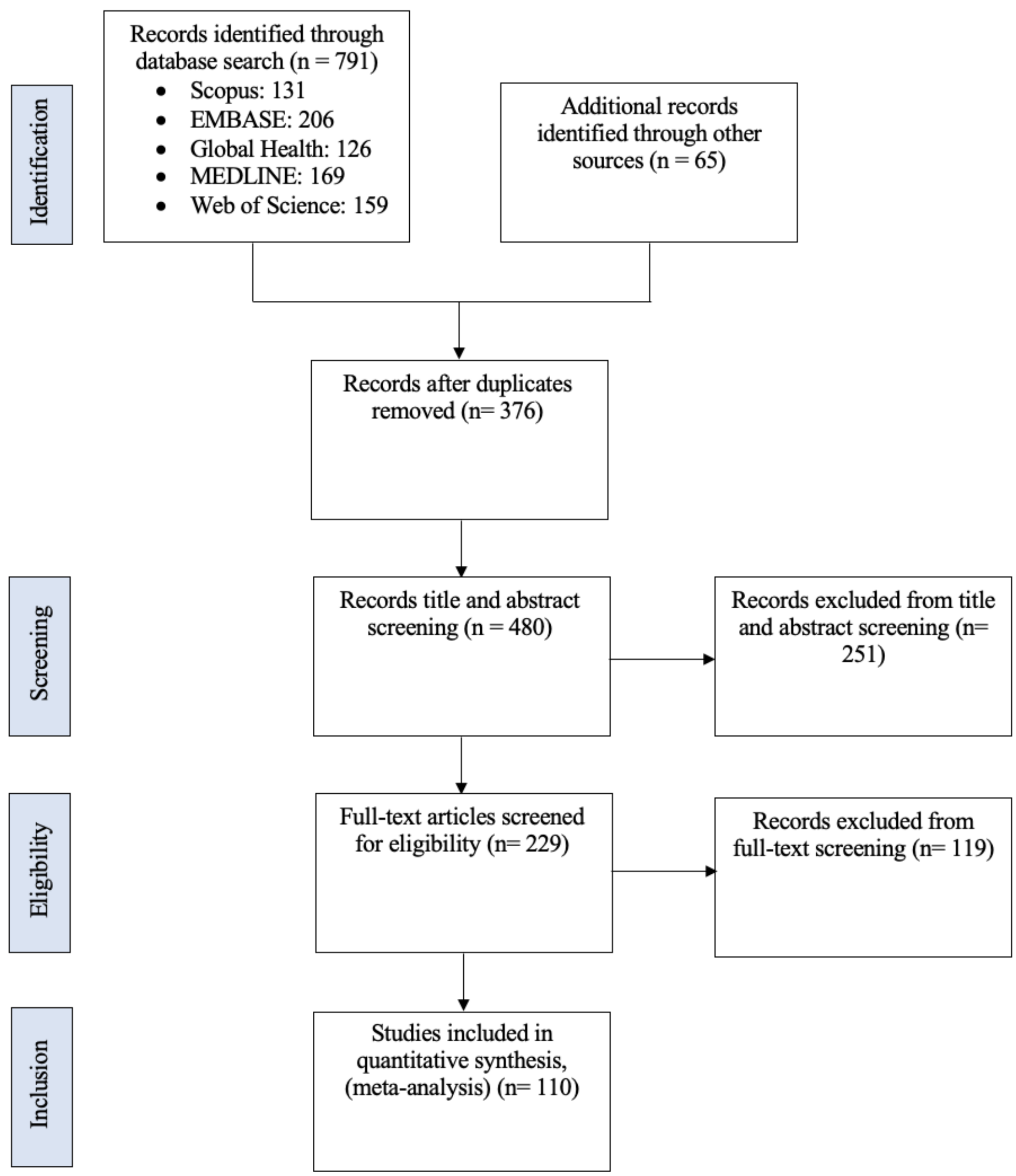

Figure 4.1: Study Selection as per PRISMA protocol for studies examining HAP and asthma or ALRI

4.3.2 Screening

Following the de-duplication of the search results, the title and abstracts were screened by two reviewers (S.A., S.G.) independently on the Covidence web software. Full texts were also screened by two reviewers (S.A., Z.G.) independently. Any conflicts in the screening were adjudicated by a third reviewer (O.K).

4.3.3. Data extraction

Two reviewers independently extracted data using an electronic database on Microsoft Excel, and conflicts were adjudicated by a third reviewer (S.A., G.Z., O.K.). Measures of effect such as odds ratios (O.R), and risk ratios (R.R) were extracted from studies. When measures of effect were not explicitly provided in the manuscript, 2x2 contingency tables were constructed and filled. O.R were calculated from such contingency tables. Other variables extracted included study participant characteristics, fuel/stove type, number of participants in the exposed and comparator groups, characteristics of the study and study design.

4.3.4 Quality Assessment

The Risk of Bias (ROB) assessment was conducted using the Newcastle Ottawa Scale (NOS) by two independent investigators (S.A, I.S). Cross-sectional studies' ROB was assessed using a modified Newcastle Ottawa scale (Herzog et al., 2013). The 'star system' used in the NOS judged each study on three broad perspectives: The selections of groups into the study, the ascertainment of exposure or outcome, and the comparability between the groups of study in either exposure arm. The face/content validity of the NOS has been established by a critical review (Wells et al., n.d.). The risk of bias assessments for the included studies can be found in the Appendix tables 1B-3B in the appendix respectively.

4.3.4. Meta-Analysis

The meta-analysis was conducted using the Stata 17 software (*Stata Statistical Software*, n.d.). A random-effects model was utilized in the meta-analysis of odds ratios obtained from the data-extraction. Forest plots were thus generated and included a chi-squared test for heterogeneity. Heterogeneity and publication bias was further examined using a funnel plot, and the calculated using the egger's test function in Stata.

4.4 Results

Our search identified 791 studies and an additional 65 were identified through bibliographies and references. After duplicates were removed, the titles and abstracts of 480 studies were screened. 251 of these studies were excluded as they did not meet the eligibility criteria. Of the remaining studies, which moved on to the full-text screening stage, 110 were included in the final review for data extraction and meta-analysis. Of these included studies, there were 15 cohort studies, 37 case-control studies and 65 cross-sectional studies. . Figure 4.1, the PRISMA reflects the search results. These studies included 15,18,096 participants across 44 countries, of which a majority (33, 75%) were LMICs (as per World Bank 2021 income classification). A summary of included studies can be found in Appendix Tables 1B-3B.

The measures of effects or risk estimates were obtained from 119 studies. Collectively, these estimates were used to derive pooled measure of effects for respiratory disease – asthma and ALRI in people exposed to HAP compared to those unexposed or using cleaner fuels/technologies. The pooled measures of effect showed an increased risk of ALRI in those exposed to HAP.

4.4.1 Study outcomes

4.4.1.1. Asthma

38 of the included studies investigated the association between HAP and asthma. These included 28 cross-sectional studies, 10 case control studies and included a total of 193544 participants under the age of 18. The ROB estimates for the studies were all above 6 stars, indicating a low risk of bias for the included studies. The measures of effect were pooled by type of study. It was observed that the use of solid fuels, in particular the exposure to household biomass smoke had a marginal, but statistically insignificant impact on the risk of asthma incidence among those younger than 18 years of age. Among case control studies, it was noted that the children exposed to HAP due to solid fuel combustion were 1.05 [95% CI: 0.77-1.44] times more likely to develop asthma than the unexposed. Similar outcomes were noted in the cross-sectional studies which reported measures of effect of 1.09 [95% CI: 0.92-1.27]. The results of the meta-analyses can be seen in Figures 4.2 and 4.3, for case-control studies and cross-sectional studies respectively.

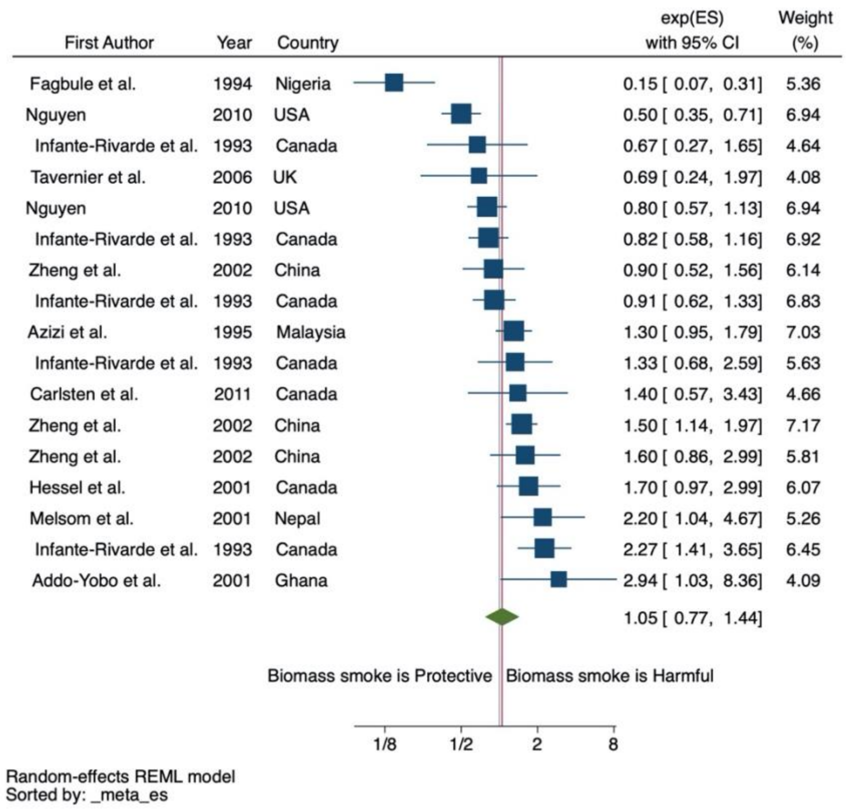

Figure 4.2: Meta-analysis of case-control studies examining the association between HAP and asthma

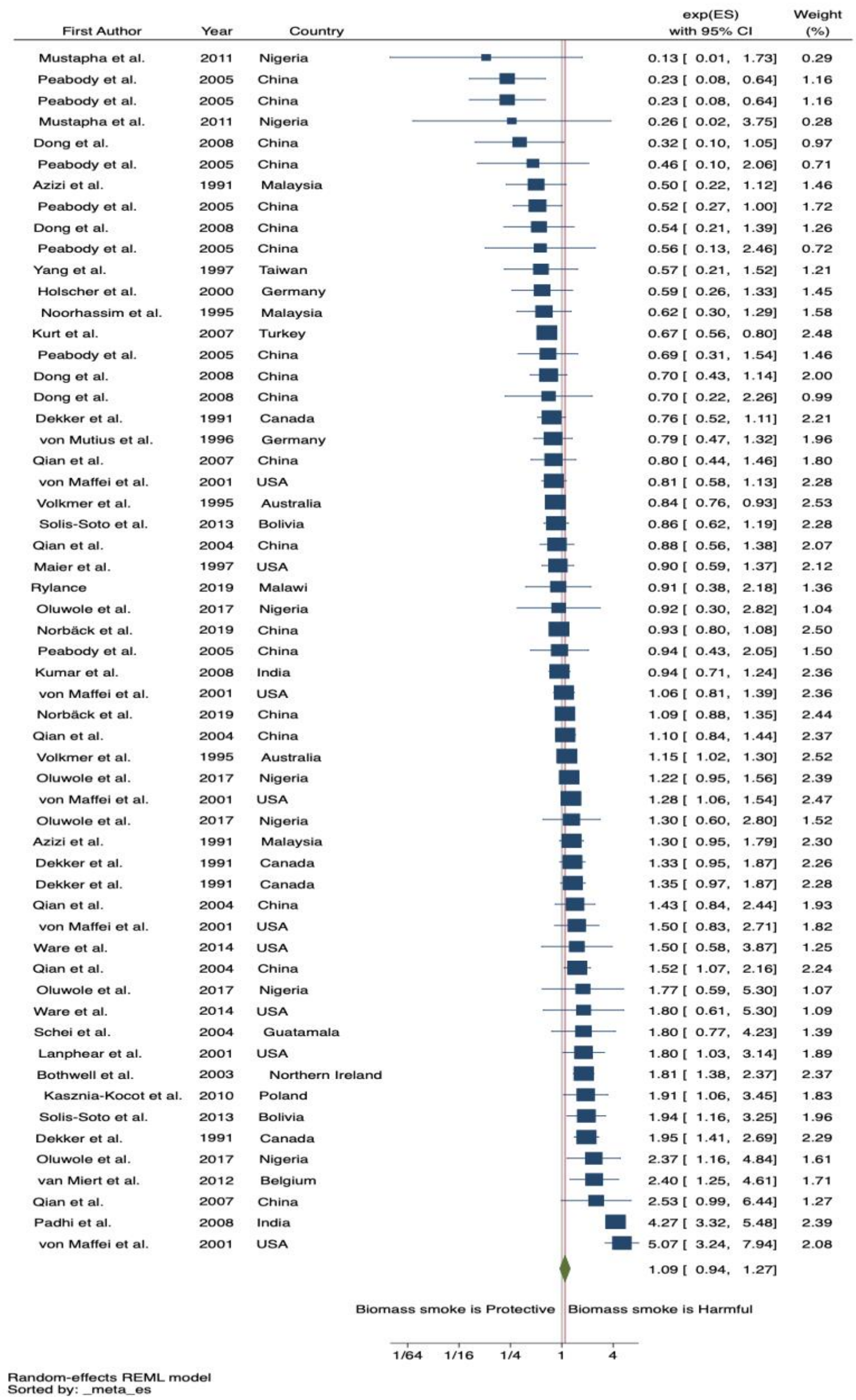

Figure 4.3: Meta-analysis of cross-sectional studies examining the association between HAP and asthma

There is a high degree of heterogeneity observed in both the cross-sectional studies and case-control studies meta-analyses. This is observed in the large chi-squared statistics relative to its degree of freedom, and the low P values (0.000 for both case-control and cross-sectional studies). The I-squared statistic indicates the variability in effect estimates due to heterogeneity, rather than sampling error or chance. The case-control studies and the cross-sectional studies' meta-analyses report I-squared statistics of 80.8% and 84.0% respectively. This represents considerable heterogeneity, as 80.8% and 84.0% of the variation in effect estimates of case-control and cross-sectional studies respectively are due heterogeneity rather than chance.

4.4.1.2. ALRI

72 of the included studies investigated the association between HAP and ALRI. These included 29 cross-sectional studies, 28 case control studies and 15 cohort studies and included a total of 1369836 participants under the age of 18. The ROB estimates for the cohort studies, were of lower quality ranging between 4-6 stars, while the other studies were all above 6 stars. The measures of effect were pooled by type of study. Among case control studies, it was noted that the children exposed to HAP due to solid fuel combustion were 1.57 [OR, 95% CI: 1.32-186] times more likely to develop ALRI than the unexposed. A similar result was noted in the cross-sectional studies, with the exposed 1.41 times more likely to develop ALRI than the unexposed [OR, 95% CI: 1.28-1.57].

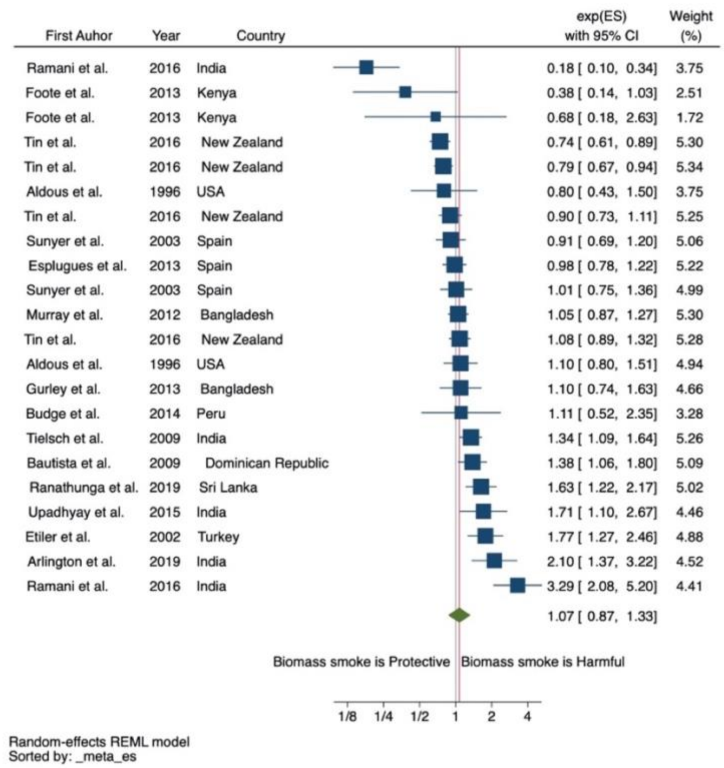

Figure 4.4: Meta-analysis of cohort studies examining the association between HAP and ALRI

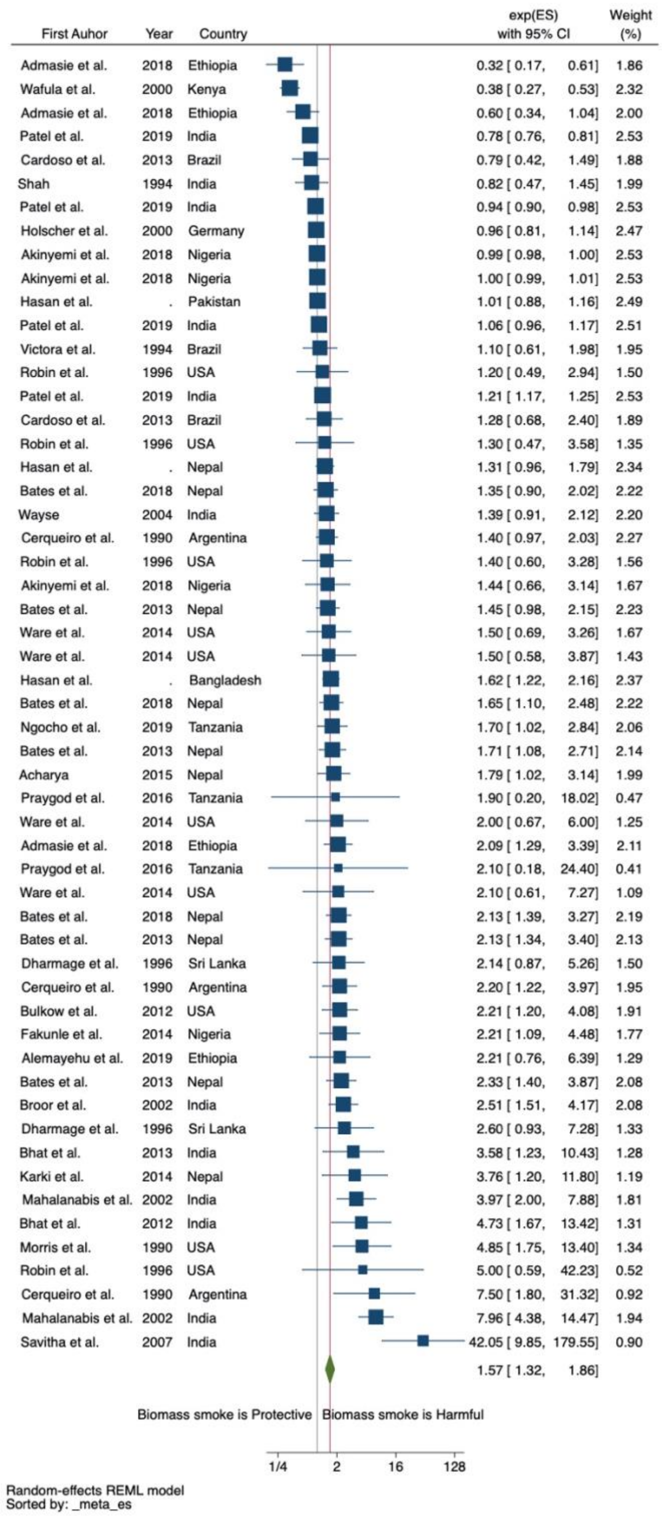

Figure 4.5: Meta-analysis of case-control studies examining the association between HAP and ALRI

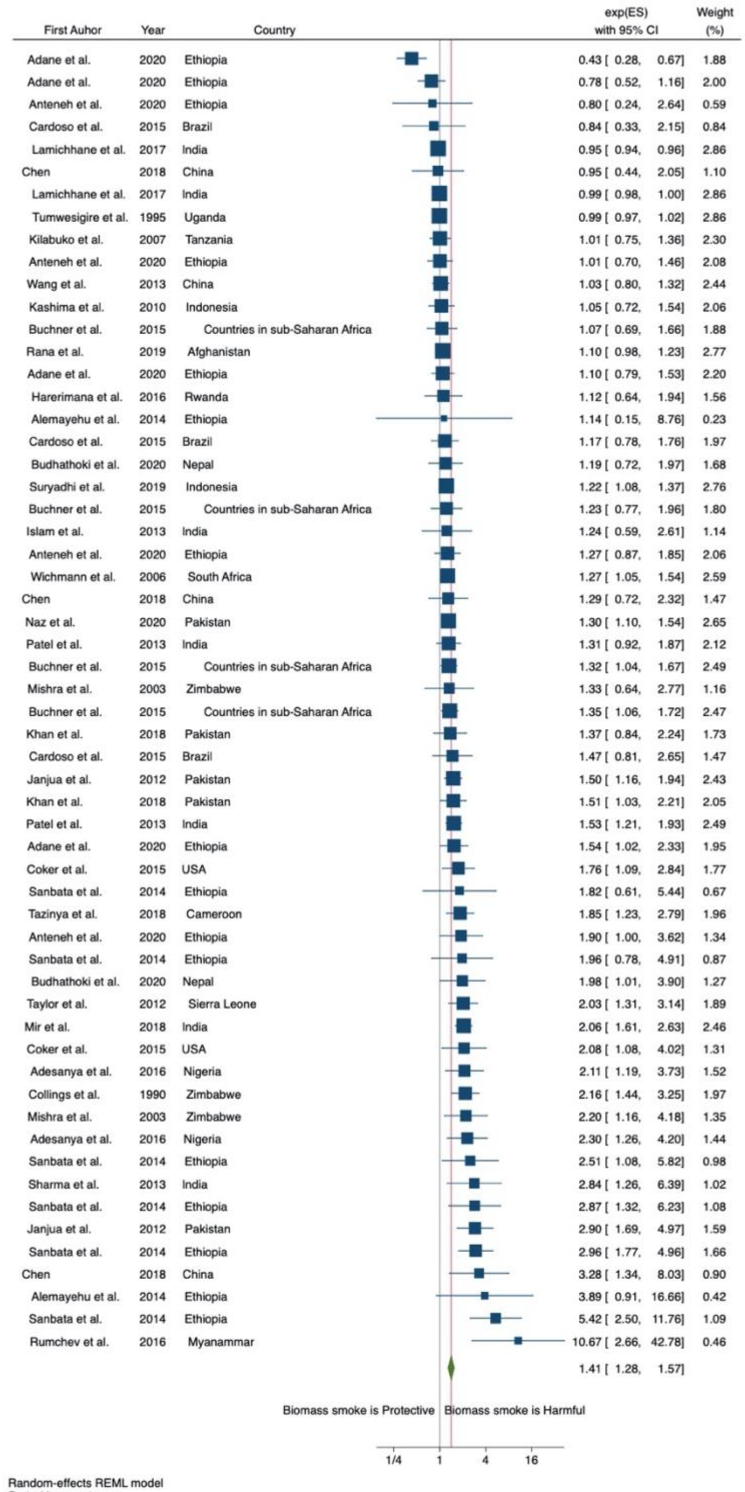

Figure 4.6: Meta-analysis of cross-sectional studies examining the association between HAP and ALRI

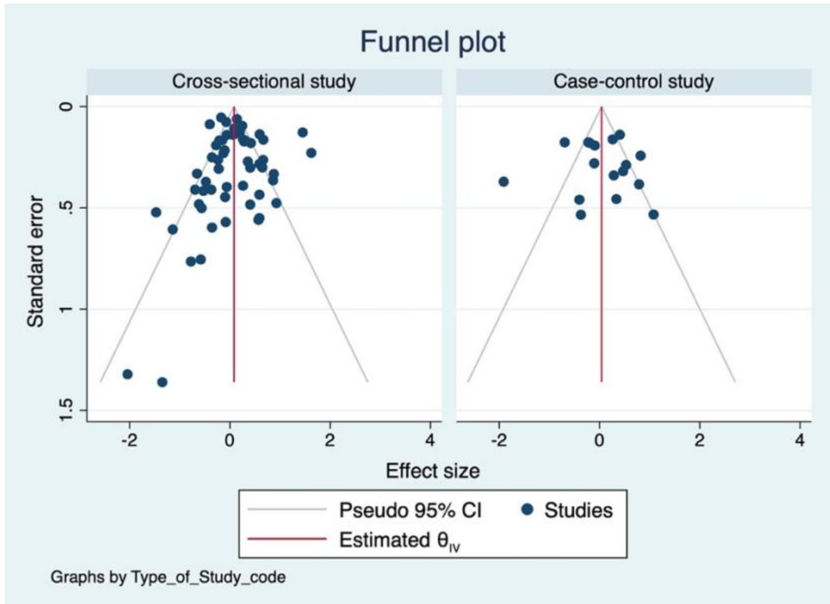

Figure 4.7: Funnel plot of studies examining the publication bias in the studies examining the association between HAP and asthma

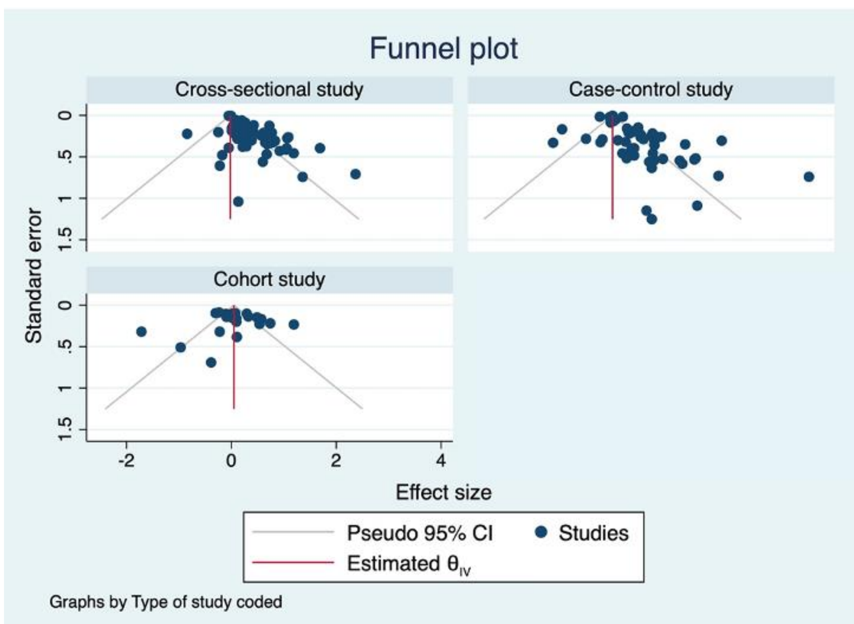

Figure 4.8: Funnel plot of studies examining the publication bias in the studies examining the association between HAP and ALRI

4.5 Discussion and Conclusion

This systematic review and meta-analysis on the impact of HAP on childhood asthma and ALRI has a few notable findings. Firstly, HAP, or exposure to biomass smoke is associated with 1.57 [95% CI: 1.32-1.86] and 1.41 [95% CI: 1.28-1.57] times increased risk of incidence of ALRI in case-control and cross-sectional studies respectively. However no increased risk of the incidence of asthma among children was noted.

There are several reasons for the increased risk among the children. Children, and especially those under the age of 5 tend to spend a considerable amount of time indoors with their mothers. This results in greater exposure to air pollutants, such as gas (CO, NO_x). particulate matter, and various other toxic organic compounds. The resultant pro-inflammatory condition is said to induce pneumonia in children (Balmes, 2019; Buchner & Rehfuess, 2015). Furthermore, children born to mothers exposed to HAP during their pregnancy are likely to have lower birthweights, which can make them further susceptible to infections such as ALRI.

In this study, it was determined that the exposure to the household combustion of biomass resulted in a significant increase in the risk of ALRI in children compared to clean, non-solid fuels, such as electricity or gas. However, due to various factors – such as affordability, wide availability and socio-cultural factors, biomass fuels remain the main fuels in Africa, Asia and Latin America (Faizan & Thakur, 2019). It has been observed that more than 90% of the primary energy supply in LMIC is fulfilled by traditional biomass fuels (Ahamad et al., 2021; McCarron et al., 2020).

There was no association noted between the exposure to household air pollution and asthma. One conro

Limitations of the study include the heterogeneity in exposure between the included studies, which can be attributed to factors such as the choice of fuel mix, duration of exposure, concentration of particulate matter, ventilation, frequency of exposure, and seasonality. In considering the exposure to HAP as a binary variable, this heterogeneity was not accounted for. Further misclassification of exposure arises from the variation in comparator groups between included studies. Some studies explicitly mention the cleaner fuel, or combustion technology as the comparator. Whereas other studies mention the lack of exposure to a certain fuel as the comparator. Our choice of a binary exposure variable was informed by a few factors. 1) Very few studies reported the outcomes by pollutant concentrations [$PM_{2.5}$] from HAP exclusively. 2) The WHO recommends a transition from polluting solid fuels to cleaner fuels and technologies. The chosen exposure variables therefore reflect such a choice, reporting on the additional risk from the use of polluting fuels, when compared to that from the use of cleaner fuels. Outcomes such as doctor-diagnosed asthma and ALRI may have been under-reported, due to the lack of formal healthcare providers in various study settings. This misclassification of the outcome could lead to a bias towards the null. Questionnaire based responses for both exposure and outcome could result in further misclassification errors.

Most of the included studies in the meta-analysis were cross-sectional in nature. Longitudinal, temporal relationships could not be established from these studies. Moreover, the level of adjustment for confounding variables varied between studies. Therefore, variables such as local cultural practices, exposure to tobacco smoke, socio-economic status, among others could have been unaccounted for in the association between exposure and outcome(s).

The systematic review search did not include non-English studies, grey, and non-peer reviewed literature due to a limitation in resources. This selection bias could have resulted in the significant heterogeneity observed in the risk estimates, for several outcomes, whose underlying distribution did not conform to a symmetric distribution. Thus, there is a need for more large, longitudinal data of higher quality to increase the certainty of the pooled risk estimates. Funnel plots were generated to examine the publication bias for the studies with the asthma and ALRI incidence outcomes (Figures 4.7 and 4.8 respectively). A visual inspection of figure 4.7 shows roughly symmetrical funnels. However, there appear to be a few outliers in the funnel plot for cross-sectional studies, and therefore a potential for publication bias. This is confirmed by the regression-based egger's test for small-study effects, wherein P = 0.00066 for cross-sectional studies, and was equal to 0.8394 for case-control studies. Figure 4.8 shows the funnel plots for the studies examining the effects of HAP on ALRI. A visual inspection of figure 8.8 shows asymmetrical funnels and outliers in the funnel plots for the cross-sectional and case-control studies, and a more symmetrical plot in the cohort studies. This is reflected in the egger's tests results. The cross-sectional and case control studies have a egger's test P value of 0.000, and that of the cohort study is equal to 0.1925. Therefore, there is a potential for publication bias in the cross-sectional and case-control studies.

CHAPTER 5: DISCUSSION

5.1 Introduction

As discussed in Section 1.6, this thesis document consisted of systematic reviews and meta-analyses that evaluated the most up-to-date evidence on the adverse health outcomes associated with HAP. The pooled meta-estimates of the effects of HAP on childhood asthma and ALRI incidence outcomes were calculated, and that on the lung function outcome was synthesized in a narrative manner. These studies sought to determine the pooled risk estimates of asthma and ALRI incidence among children exposed to HAP compared to those not exposed or exposed to HAP from improved cookstoves, and whether early life exposure to HAP affects lung function in children.

As discussed in Chapter 1, the WHO estimates that 2.6 billion people rely on polluting fuels for household cooking and heating purposes. Although there has been a a gradual increase in the uptake of cleaner fuels and technologies, the population growth particularly in sub-Saharan Africa has outpaced in the increase in clean cooking fuel access. Therefore, while the increase in clean cooking access has been seen in the large populous countries of Asia such as India and China, the access deficit in sub-Saharan Africa has doubled since 1990, reaching a total of 923 million people in 2020 (International Bank for Reconstruction and Development, 2022). Similarly, while electricity access increased in every region of the world in the between 2010-2020, the share of sub-Saharan Africa in the global access deficit increased from 71% to 77% in the same time period (International Bank for Reconstruction and Development, 2022). Globally, exposure to HAP is among the top ten risk factors for disease, with the highest burden observed in the world's poorest regions. This includes the outcomes of ALRI, decline in lung function, and other cardio-respiratory, pediatric, and maternal diseases (Bennitt et al., 2021).

The results of the systematic reviews highlight the increased risk of adverse respiratory outcomes in children due to their exposure to HAP. The relative risk of the selected respiratory outcomes among those exposed to HAP, compared to those exposed to clean fuels and/or technologies underscore the importance of, and the urgency in the transition to clean fuels and technologies, particularly in LMIC. In this discussion chapter of the thesis, we review and discuss the results and limitations of the conducted systematic reviews and explore directions for future research. Furthermore, the implications of these studies are discussed in the broader context of global health – the SDGs, and the research to policy development approach.

5.2 Outcomes and Implications

Firstly, HAP is associated with an increased risk of adverse respiratory outcomes in children. Notably, the strongest quantitative association noted for the incidence of ALRI, followed by a reduction in lung function. There was no association noted between the exposure to HAP and the incidence of asthma.

The results of the systematic review examining the association between HAP and lung function demonstrate a reduction in the growth of lung function among children. Specifically, the exposure to smoke from the combustion of solid fuels results in a lower growth of FVC, FEV_1, and $FEF_{25\text{-}75}$ among participants aged below the age of 18. This is a crucial period of lung development, as it is a period of accelerated growth until full skeletal maturity (Phelan et al., 2002; Sears et al., 2009; Stocks et al., 2013). Diminished lung function in childhood results is a strong predictor of lower lung function in adulthood, and places one at increased risk of adverse respiratory outcomes such as COPD later in adulthood (James et al., 2005). This is consistent with the increased risk of COPD associated with the use of polluting fuels and technologies (OR = 1.70, 95% CI: 1.47-1.97) (Lee et al., 2020).

The results of this systematic review confirm that of previous studies examining the association of ALRI and HAP. The pooled risk estimate supports a consistent association between solid fuel use and an increased risk of ALRI in exposed children. This measure of effect suggests a benefit from the uptake of cleaner fuels and technologies, which would have a protective effect on the risk of asthma in exposed children. As mentioned in Section 1.1, ALRI, specifically pneumonia is responsible for 45% of the deaths of children under 5 globally. Given the association of HAP and the incidence of childhood pneumonia, and the burden of disease from pneumonia, there is evidence to suggest for the urgency in the uptake of clean fuels.

Asthma is a complex manifestation, one in the array of atopic conditions, originating from genetic and environmental causes, and unified by symptoms such as wheezing and constricted airways. One of the factors that are associated with the etiology of asthma, include the airway inflammation hypothesis, which would suggest a plausible link between HAP and asthma. However, the literature examining this association, remains inconclusive, leaving many unanswered questions.

A recent longitudinal study of 150,090 children from the European Union (EU) child cohort network demonstrated that children with early ALRI had lower school age lung function, and an increased risk developing asthma, and COPD later on in life (van Meel et al., 2022). People at risk of adverse respiratory outcomes at an older age include adults over the age of 65, and those with pre-existing conditions.

5.2.1 Global Health Implications

In recognizing that the extreme poverty is the greatest global challenge, and that its eradication is a crucial part of sustainable development, the UN 2030 Agenda for sustainable development seeks a full implementation of the SDGs by the year 2030. As discussed in Section 1.5, the UN SDGs are a comprehensive and inter-linked set of developmental goals, with economic, environmental, and social dimensions. The achievement of SDG 7, which strives to "ensure access to affordable, reliable, sustainable and modern energy for all", will therefore also advance the achievement of other SDGs. The achievement of SDG 7 is linked to the achievement of SDGs 3, which seeks to "ensure healthy lives and promote well-being for all ages", 13 - which aims to take "urgent action to combat climate change and its impacts" and 5, which aims to "achieve gender equality and empower all women and girls" and others. However, as discussed in Section 5.1, the full implementation of the 2030 agenda seems uncertain due to the inequity in access, particularly in LMICs.

Furthermore, the COVID-19 pandemic, and its consequent diversion of fiscal resources, has slowed the progress made towards SDG 7 – the universal access to energy. This includes the drop in international fiscal aid to developing countries in support of clean energy access. International monetary aid towards the transition to clean fuels and technologies is a key component of the collaboration that is needed to achieve SDG 7. Importantly, public funding and policy creates the infrastructure and programs and reduces the risks, thereby creating an enabling environment for private sector investments. At the current rate of progress, 670 million individuals will remain without access to electricity by 2030, which is 10 million more than projected in 2021. Nearly 90 million people in Asia and Africa who had previously gained access to electricity can no longer afford to pay for their basic energy needs (International Bank for Reconstruction and Development, 2022; WHO, 2022).

A 2021 stakeholders' consultation for the UN high-level dialogue on energy revealed some important concerns regarding the transition to the clean fuels – The sustainable access to the energy and the transition to clean fuels, as per SDG 7 has been inequitable based on various intersecting criteria, such as poverty, geographic disparities, gender, and indigenous ethnicity among others. Government subsidies and energy infrastructure development programs have been largely inaccessible to the poor, and to those in dispersed rural settings. Inefficiencies in multi-level governance and bureaucracy hindered the access to clean fuels and technologies. Consequently, small local organizations were excluded from receiving funding and technology transfer, thus preventing them from bringing energy access to remote areas. Furthermore, rural areas are often seen as unprofitable by governments and investors based on economic viability alone. Thus, the markets seen as unattractive for investment are systematically excluded from the financial flow, technology, and skills transfer. Collectively, these barriers to access clean energy aggravated the detrimental conditions of those living in rural areas, and the poor, women, children, and indigenous peoples. It was therefore advocated that the achievement of the SDG 7 would be only possible with reliable and importantly, collaborative investment towards the production and distribution of sustainable energy, equitable policy incentives, and capacity building through multi-lateral partnerships between donors and recipients.

5.3 Directions for the Future

Longitudinal, and temporal associations between HAP and the studied outcomes could not be established in the current review, as most of the studies studying HAP tend to be cross-sectional in nature. For future research, the dose-response effect of HAP should be evaluated, with the use of prospective studies and varying levels of household pollutants on respiratory outcomes. Such toxicological studies would be essential to understand the pathophysiology, or the mechanistic pathways through which the combustion of solid fuels leads to disease. Additionally, such studies could also include in vitro, animal, and controlled human exposure studies.

In line with current research, where a direct transition to clean fuels is not feasible, the WHO advocates for a transition to advanced combustion based cookstoves, which utilize solid fuels such as biomass (WHO, 2014). However, evidence suggests that biomass fuelled cookstoves may not deliver the health benefits as believed (Mortimer et al., 2017). Therefore, there is a need for clinical trials investigating the health outcomes of interventions to guide policy and decision making.

As indicated in Chapter 1, Section 1.3, the factors that influence household fuel choice are complex and multi-faceted. Affordability, availability, and convenience are some of the more visible factors, that are conventionally considered in policy development regarding a transition to more clean fuels and technologies. Some of these factors tend be 'hidden' from conventional consideration. Examples of these hidden factors can include cultural traditions and gender roles.

The Social Ecological Model states that people's behaviours and experiences are shaped by their interactions at various levels, starting at an individual or inter-personal level, where knowledge, attitudes and practices affect one's choices and decision making, to the level of policy and systems, wherein policies and governance can facilitate or discourage one's choices and behaviour (UNICEF, 2016). Sallis et al (2008) explores how the Social Ecological Model can be applied to the decision making in the context of household fuel choice. This is illustrated below in Figure 5.1.

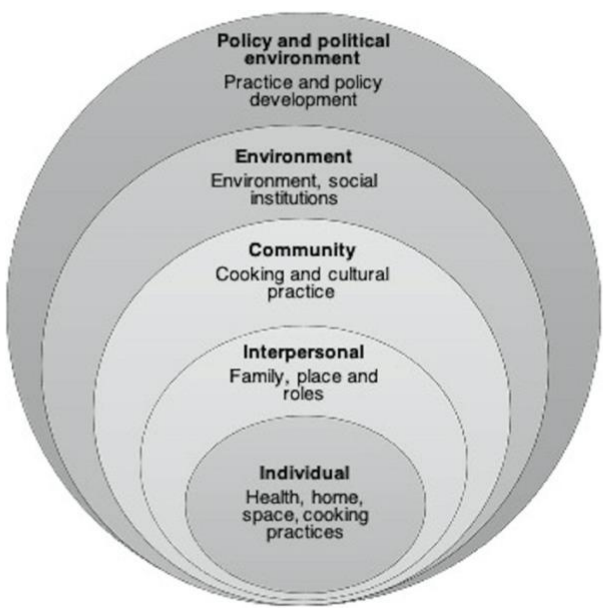

Figure 6.1 Social Ecological Model adapted to HAP (Sallis et al., 2008)

The systematic reviews conducted link the exposure to HAP with the adverse respiratory outcomes of ALRI and reduced lung function. However, the above-mentioned factors (and those in Section 1.3) are reasons for the continued use household solid fuel. Therefore, interventions to reduce the exposure to HAP must incorporate frameworks on behaviour change, in addition to their consideration of clinical exposure and outcome. These frameworks can highlight how factors beyond the knowledge of HAP - such as cultural norms, perceived behavioural control and attitude can influence household fuel choice. The CI-CHANGE framework (Fig 5.2), on cooking transition is a recently developed behaviour change framework that specifically deals with the transition to clean fuels and technologies (Kar & Zerriffi, 2018). The CI-CHANGE framework is informed by health behaviour change psychology, social psychology, and information systems research to identify and prioritize areas for intervention. It therefore identifies factors such as cultural norms and intrinsic motivational factors that influence household fuel choice. This contrasts with previous methodology to relied on clinical outcomes, sociodemographic conditions, and market-based evaluations to guide interventional policy.

Further qualitative research should be conducted at the community level and should seek to identify the priorities of solid fuel users, especially women, and to study their lived experience, local culture, tradition, and the complexities of gender-based household decision making. Therefore, interventions and policy need to fit within the local cultural context, and be community led. This research can be critical towards gaining an understanding of those ‘hidden factors’ that influence the choice of household fuel and can be used in a framework to inform policy development. Such research methods can employ techniques such as walking interviews, video dairies, mapping and photovoice (McCarron et al., 2020). For example, Saleh et al (2021) studied the HAP within a social and environmental context, and utilized immersive participant observation, along with air quality monitoring, interviews and participatory workshops. The mixed-methodology sought to understand and aggregate the users' lived experience along with the knowledge of clinicians and academics. Similarly, a qualitative study of two communities in Kenya utilized in-depth interviews and focus group discussions to understand factors that contribute to the practice of fuel stacking (OChieng et al., 2020). The implications of these qualitative studies would bear effect on the strategies to sustainably implement the distribution of the clean fuels and technologies.

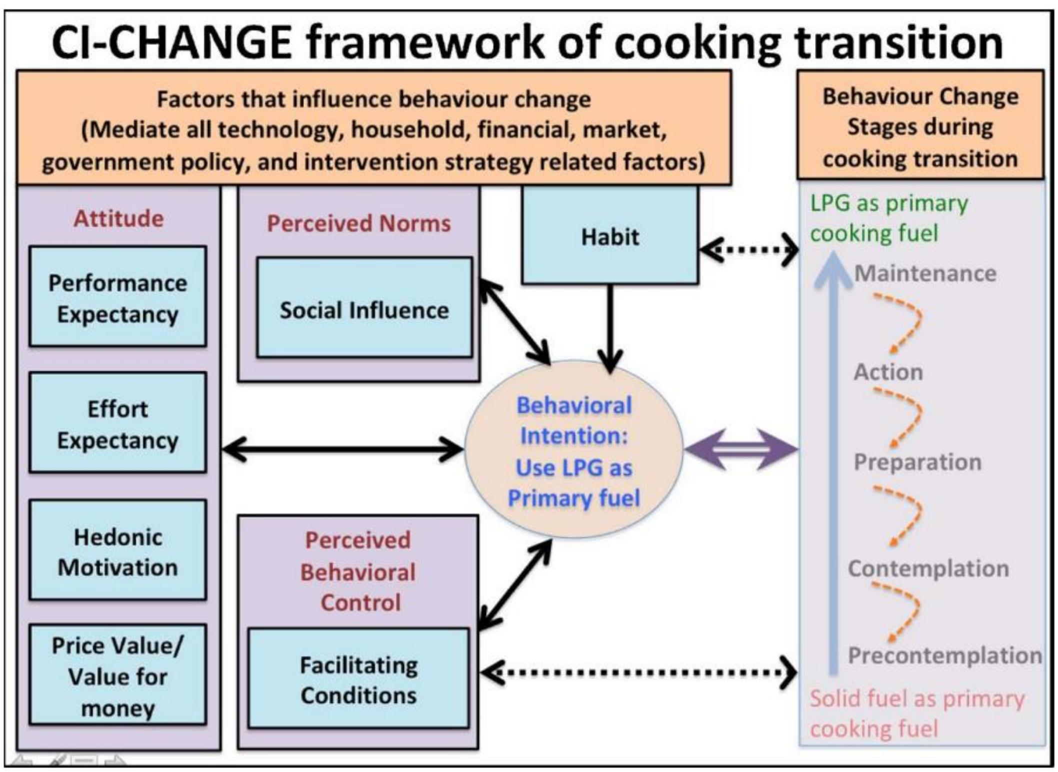

Figure 5.2: The CI-CHANGE framework of cooking transition (Kar & Zerriffi, 2018)

Furthermore, research-to-policy (or research utilization) approaches have focussed on a policy development process in a clinical setting, with less application of the process at a programme level (Innvaer et al., 2002). The translation of knowledge at the level of programmes is critical for the scaling up, and implementation of evidence-based programmes in a country (C. Kim et al., 2018). This applies to the translation of the latest HAP related evidence into the policies and institutions. With more research that is grounded in a local context and an understanding of lived realities, there may be an increase in the capacity to use and apply evidence among the 'end-user'. This is commonly understood to be a challenge in the field of global health, where there can be a dis-connect between the evidence producer and the end-user.

The process of research utilization should therefore reflect the dynamic relationships between the producers of research, the brokers of knowledge and the end-user. This is reflected in the Family Health International (FHI) 360 research utilization framework (C. Kim et al., 2018), as seen in Figure 5.3. The overlap between the research producers, knowledge brokers and end users as seen in Figure 5.3 reflects the engagement of civil society, policy makers and implementers in identifying research priorities, and the conceptualization of research. Subsequently, the translation of knowledge involves the synthesis of knowledge products, and audience specific messaging in collaboration with various stakeholders such as advocates, community leaders and government. This would result in collaborative, effective, evidence-based programmes, and policies. In the context of HAP, this can start from the conception of research, that can be grounded in the lived experiences of the users of solid fuel. This evidence-based research can then be disseminated using audience specific messaging, in collaboration with communities. For instance, while women are typically at the highest risk of exposure to HAP, males tend to be the primary household decision makers with regards to fuel choice. Similarly, community leaders can shift the preferences and values of a community, thereby making clean fuels more acceptable in a setting with resistance to change (McCarron et al., 2020). Therefore, knowledge dissemination can be targeted to, and designed with these leaders and decision makers. Lastly, interventions such as policies and programs to increase access to, and the usage of clean fuels can be based on the previously discussed collaborative, evidence-based approaches.

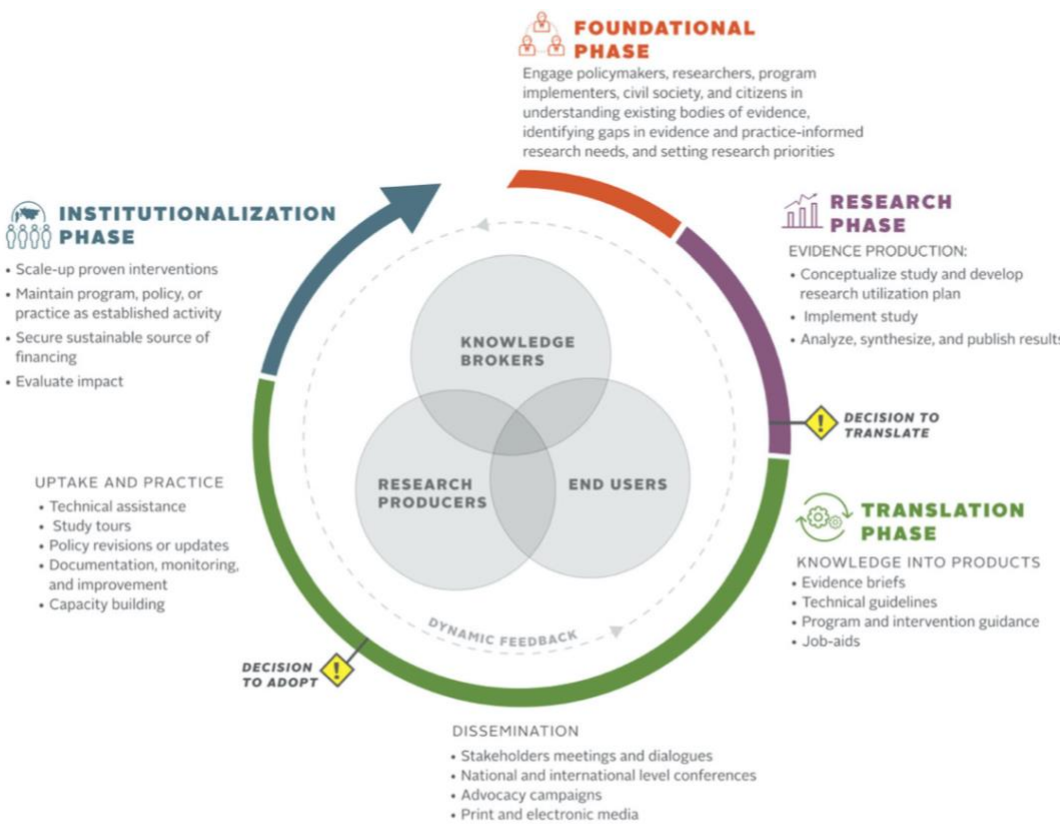

Figure 5.3: The Family Health International (FHI) 360 research utilization framework (C. Kim et al., 2018)

5.4 Limitation and Challenges

As commonly noted with the meta-analysis of observational studies, the pooled estimates calculated may be subject to some residual confounding, due to variables not considered in study population, varying exposure and outcome definitions used (including those definitions employed by clinicians), and reporting measures. For instance, there could be varying definitions of asthma used by clinicians in different settings. Moreover, there is a potential for a vast number of cases of asthma and ALRI to go unreported, due to issues of access of healthcare in various settings. Another confounding variable is the rural-urban divide, where asthma is much more prevalent in urban areas than rural, whereas the utilization of solid fuels mostly occurs in rural areas. Additionally, the protective effect of living in a farm environment, and that of livestock against asthma is well documented, however this may not have been considered in all the included studies.

The estimation of exposure is done in a binary fashion, where the choice of fuel is a proxy for exposure. The use of proxy measures for HAP exposure, such as on the one used in the current review can produce biased epidemiological estimates (Evangelopoulos et al., 2020). This does not consider a dose-response effect, or the heterogeneity in exposure, which is reflected in the varied practices of cooking, cultures, ventilation, duration spent indoors et cetera. For instance, the location of cooking and cultural practices within the household is said to be associated with the level of pollution in the air (Adane et al., 2021; Rehfuess et al., 2014). For instance, it has been reported that only 43% of the households in Asia practiced indoor cooking (from 71% in 2005) (PrayGod et al., 2016). However, due to various economic and socio-cultural factors, such a decrease in indoor exposure to cooking may not have been uniform across jurisdictions. Whereas over one quarter of the households in Asia have replaced traditional cooking methods by modern cooking appliances since 2010 (Faizan & Thakur, 2019), traditional cooking methods such as the three-stone stove are reported to be the predominant cooking device in parts of Africa (Du et al., 2021).

Additionally, while some studies explicitly mentioned the comparator fuel, other studies chose no-exposure to a specific polluting fuel as the comparator. Moreover, the practice of fuel stacking, where a household uses varied sources of fuel and may use solid fuels despite having access to cleaner fuels and technologies. Taken together, all these issues can increase an identification (misclassification) bias of exposure. However, only a few of the included studies included measures of pollutant exposure and clinical outcomes. None of these studies were conducted in LMICs. Moreover, the WHO recommends a direct transition from solid fuels to clean fuels and technologies. Therefore, while a binary exposure variable is not ideal to study a dose-response relationship, a study with an exposure and comparator group as chosen in the current review is therefore optimal to study such a transition as recommended by the WHO.

Additionally, different solid fuels burn with varying combustion efficiencies and therefore emit varying concentrations of pollutants into the indoor environment. They can therefore have various degrees of impact of the incidence of respiratory outcomes such as ALRI, asthma, or lung function (Chartier et al., 2017). A sub-group analysis based on cooking practices, fuel types, rural-urban divide, and income category may reduce the heterogeneity in exposure level.

The use of questionnaires in the study to ascertain the use of solid fuel can lead to a social desirability bias, resulting in the misclassification of exposure, and a bias towards the null. It is also possible that the parents of those with respiratory ailments such as asthma or ALRI could have over or under-reported their estimated use of solid fuels. To avoid selection bias, two independent reviewers conducted the screening and selection processes. However, considering that the exposure to HAP is predominant in LMIC, publication bias may arise from the fact that grey literature such unpublished manuscripts, and non-English manuscripts were not included in the study. Although, it is worth mentioning that the studies included in the current reviews were diverse in their area of study.

5.5 Conclusions

HAP is a major modifiable health risk factor, with a high burden of disease globally. This burden arises from the continued widespread use of solid fuels, and their impact on various health outcomes. The systematic reviews and meta-analyses conducted synthesized the most up to date evidence on the effects of HAP exposure on lung function, and the incidence of asthma and ALRI in children. It was confirmed that the exposure to HAP is associated with an increased incidence of ALRI and reduced lung function in children. However, there was no association observed between the exposure to HAP and the incidence of asthma in children. As demonstrated by the level of relative risk, the risk of these adverse outcomes can be reduced by the uptake of cleaner fuels and technologies such as LPG and electricity.

However, the reasons for continued use of solid fuels are varied. While affordability plays a role in the transition to clean fuels, the priorities and lived experiences of the solid fuel users must be considered. Qualitative studies can be undertaken to understand these factors, and can inform the development of effective interventions, policies, and programmes. Additionally, the transition to clean fuels and technologies can only be achieved through multi-lateral partnerships, investments, and knowledge/skill transfer. The universal transition to affordable, reliable, and modern energy is SDG 7, and a key component of the UN 2030 Agenda for sustainable development.

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APPENDIX A: SEARCH STRATEGIES

Line	**Search Terms**
1	Air Pollution, Indoor/
2	((indoor or household or house hold or home or inside) adj2 air pollution).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
3	((indoor or household or house hold or home or inside) adj5 air pollution).mp.
4	or/1-3
5	coal/
6	biomass/
7	biomass.mp.
8	charcoal/
9	charcoal.mp.
10	kerosene/
11	kerosene.mp.
12	plant residue/
13	(crop residue or plant residue).mp.
14	((coal or peat or wood or dung or charcoal or biomass or kerosene or crop residue) adj5 (cook* or heat* or stove* or burn* or combust* or furnace)).mp.
15	or/5-14
16	adolescent/ or exp child/ or infant/
17	(child* or infan* or adolescen* or teenage* or preadolescen* or preteen* or preschool* or youth*).mp.
18	Pediatrics/
19	p?diatric*.mp.
20	or/16-19
21	respiratory tract infection/
22	exp respiratory tract infection/
23	(pnuemonia or respiratory tract infection*).mp.
24	or/21-23
25	4 and 15 and 20 and 24
26	exp asthma/
27	lung allerg*.mp.
28	asthma*.mp.
29	or/26-28
30	4 and 15 and 20 and 29
31	exp spirometry
32	exp lung function/
33	exp forced expiratory volume/

34	exp peak expiratory flow/
35	exp forced vital capacity/
36	(lung function or spirometr* or forced expiratory volume or peak expiratory flow or forced vital capacity or FEV1 or FVC or PEF or FEF).mp.
37	or/31-36
38	4 and 15 and 20 and 37
39	25 or 30 or 38
40	limit 39 to (human and english language and yr="1980 -Current")

Appendix Table 1A: Search strategy for EMBASE

Line	**Search Terms**
1	Air Pollution, Indoor/
2	((indoor or household or house hold or home or inside) adj2 air pollution).mp. [mp=abstract, title, original title, broad terms, heading words, identifiers, cabicodes]
3	((indoor or household or house hold or home or inside) adj5 air pollution).mp.
4	or/1-3
5	Coal/
6	biomass/
7	biomass.mp.
8	charcoal/
9	charcoal.mp.
10	(coal or peat or wood or dung or charcoal or biomass) adj5 (cook* or heat* or stove* or burn* or combust* or furnace)).mp.
11	or/5-10
12	adolescent/ or exp child/ or infant
13	(child* or infan* or adolescen* or teenage* or preadolescen* or preteen* or preschool* or youth*).mp.
14	(children or pediatrics).sh.
15	p?diatric*.mp/
16	or/12-15
17	(respiratory diseases or lower respiratory tract infections).sh
18	exp.respiratory diseases/
19	(pneumonia or respiratory tract infection*).mp.
20	or/17-19
21	4 and 11 and 16 and 20
22	exp asthma/
23	lung allerg*.mp
24	asthma*.mp
25	or/22-24
26	4 and 11 and 16 and 25
27	exp lung function/
28	(lung function or spirometr* or forced expiratory volume or peak expiratory flow or forced vital capacity or FEV1 or FVC or PEF or FEF).mp.
29	27 or 28
30	4 and 11 and 16 and 29

31	21 or 26 or 30
32	limit 31 to (english language and yr=”1980-Current”)

Appendix Table 2A: Search Strategy for MEDLINE

Line	**Search Terms**
1	Air Pollution, Indoor/
2	((indoor or household or house hold or home or inside) adj2 air pollution).mp. [mp=title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms]
3	((indoor or household or house hold or home or inside) adj5 air pollution).mp.
4	or/1-3
5	coal/
6	biomass/
7	biomass.mp.
8	charcoal/
9	charcoal.mp.
10	kerosene/
11	kerosene.mp.
12	plant residue/
13	(crop residue or plant residue).mp.
14	((coal or peat or wood or dung or charcoal or biomass or kerosene or crop residue) adj5 (cook* or heat* or stove* or burn* or combust* or furnace)).mp.
15	or/5-14
16	adolescent/ or exp child/ or infant/
17	(child* or infan* or adolescen* or teenage* or preadolescen* or preteen* or preschool* or youth*).mp.
18	Pediatrics/
19	p?diatric*.mp.
20	or/16-19
21	respiratory tract infection/
22	exp respiratory tract infection/
23	(pnuemonia or respiratory tract infection*).mp.
24	or/21-23
25	4 and 15 and 20 and 24
26	exp asthma/
27	exp spirometry/
28	exp Respiratory Function Tests/
29	exp forced expiratory volume/
30	exp peak expiratory flow/
31	Exp forced vital capacity/
32	(lung function or spirometr* or forced expiratory volume or peak expiratory flow or forced vital capacity or FEV1 or FVC or PEF or FEF).mp.
33	or/27-32
34	4 and 11 and 16 and 33

Appendix Table 3A: Search Strategy for Global Health

((KEY ("indoor air pollution") OR TITLE-ABS-KEY (("Indoor" OR "household" OR "home" OR "inside" OR "domestic") W/5 "air pollution")) AND (KEY ("COAL" OR "BIOMASS" OR "CHARCOAL" OR "KEROSENE" OR "PLANT RESIDUE" OR "CROP RESIDUE") OR TITLE-ABS-KEY (("COAL" OR "BIOMASS" OR "CHARCOAL" OR "KEROSENE" OR "PLANT RESIDUE" OR "CROP RESIDUE") W/5 ("COOK* or HEAT* or STOVE* or BURN* or COMBUST* or FURNACE"))) AND (KEY ("adolescent" OR "child" OR "infant" OR "pediatrics" OR "paediatrics") OR TITLE-ABS-KEY ("child*" OR "infan*" OR "teenage*" OR pre-adolescent OR "preteen*" OR "youth" OR "paediatric*")) AND (KEY ("respiratory tract infection" OR "pneumonia") OR TITLE-ABS-KEY ("respiratory tract infection" OR "pneumonia"))) OR ((KEY ("indoor air pollution") OR TITLE-ABS-KEY (("Indoor" OR "household" OR "home" OR "inside" OR "domestic") W/5 "air pollution")) AND (KEY ("COAL" OR "BIOMASS" OR "CHARCOAL" OR "KEROSENE" OR "PLANT RESIDUE" OR "CROP RESIDUE") OR TITLE-ABS-KEY (("COAL" OR "BIOMASS" OR "CHARCOAL" OR "KEROSENE" OR "PLANT RESIDUE" OR "CROP RESIDUE") W/5 ("COOK* or HEAT* or STOVE* or BURN* or COMBUST* or FURNACE"))) AND (KEY ("adolescent" OR "child" OR "infant" OR "pediatrics" OR "paediatrics") OR TITLE-ABS-KEY ("child*" OR "infan*" OR "teenage*" OR pre-adolescent OR "preteen*" OR "youth" OR "paediatric*")) AND (KEY ("Asthma") OR TITLE-ABS-KEY ("Asthma*" OR "Lung allerg*"))) OR ((KEY ("indoor air pollution") OR TITLE-ABS-KEY (("Indoor" OR "household" OR "home" OR "inside" OR "domestic") W/5 "air pollution")) AND (KEY ("COAL" OR "BIOMASS" OR "CHARCOAL" OR "KEROSENE" OR "PLANT RESIDUE" OR "CROP RESIDUE") OR TITLE-ABS-KEY (("COAL" OR "BIOMASS" OR "CHARCOAL" OR "KEROSENE" OR "PLANT RESIDUE" OR "CROP RESIDUE") W/5 ("COOK* or HEAT* or STOVE* or BURN* or COMBUST* or FURNACE"))) AND (KEY ("adolescent" OR "child" OR "infant" OR "pediatrics" OR "paediatrics") OR TITLE-ABS-KEY ("child*" OR "infan*" OR "teenage*" OR pre-adolescent OR "preteen*" OR "youth" OR "paediatric*")) AND (KEY ("Spirometry" OR "Lung function" OR "Forced expiratory volume" OR "Peak expiratory flow" OR "Forced vital capacity") OR TITLE-ABS-KEY ("Spirometr*" OR "Lung function" OR "Forced expiratory volume*" OR "Peak expiratory flow" OR "Forced vital capacity" OR "FEV1" OR "FVC" OR "PEF" OR "FEF"))) AND (LIMIT-TO (LANGUAGE , "English")) AND (EXCLUDE (DOCTYPE , "re"))

Appendix Table 4A: Search Strategy for SCOPUS

Line	**Search Terms**
1	KP=("Indoor Air Pollution" OR "Household Air Pollution" OR "Air Pollution, Indoor")
2	TS=(("indoor" OR "household" OR "house hold" OR "home" OR "inside" OR "domestic") NEAR/5 ("air pollution"))
3	#2 OR #1
4	KP=("Coal" OR "Biomass" OR "Charcoal" OR "kerosene" OR "plant residue" OR "crop residue" OR "dung")
5	TS=(("Coal" OR "Biomass" OR "Charcoal" OR "kerosene" OR "plant residue" OR "crop residue" OR "dung" OR "peat" OR "wood") NEAR/5 ("Cook*" OR "Heat*" OR "stove*" OR "burn*" OR "Combust*" OR "Furnace"))
6	#5 OR #4
7	KP=("Adolescent" OR "child" OR "children" OR "infant" OR "teen" OR "youth" OR pediatric OR Paediatric)
8	TS=("child*" OR "Infan*" OR "adolescen*" OR "teenage*" OR "preadolescen*" OR "preteen*" OR "preschool*" OR "youth*" OR p?ediatric)
9	#8 OR #7
10	KP=("Respiratory tract infection" OR "LRTI" OR "Pneumonia")
11	TS=("Respiratory tract infection" OR "LRTI" OR "Pneumonia")
12	#11 OR #10
13	TS=("Asthma" OR "Lung allerg*" OR "reactive airway disease")
14	"Lung allerg*" OR "reactive airway disease"
15	#14 OR #13
16	TS=("Spirometry" OR "Lung function" OR "Forced expiratory volume" OR "peak expiratory volume" OR "forced vital capacity")
17	**(**KP=("Spirometry" OR "Lung function" OR "Forced expiratory volume" OR "peak expiratory volume" OR "forced vital capacity" OR FEV1 OR FVC OR PEF OR FEF)
18	#17 OR #16
19	#12 AND #9 AND #6 AND #3
20	#15 AND #9 AND #6 AND #3
21	#18 AND #9 AND #6 AND #3
22	#21 OR #20 OR #19
23	(#21 OR #20 OR #19) AND LANGUAGE: (English)
24	(#21 OR #20 OR #19) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Review)
25	(#23 NOT #24) AND LANGUAGE: (English)

Appendix Table 5A: Search Strategy for Web of Science

APPENDIX B: SUMMARY OF INCLUDED STUDIES

First Author and Year	Country	Age range of Participants	Number of Participants	% Of male participants	Objective	Exposure fuel	Comparator fuel	ROB
Addo-Yobo et al., 2001	Ghana	13.3 years	96	50	To investigate the risk factors for asthma in Ghanaian school children	charcoal, firewood, liquified petroleum gas, and kerosene	electricity domestic use	5
Azizi et al., 1991	Malaysia	7-12 years	1501	57.3	To examine the effects of mosquito coil smoke, passive smoking, and other sources of indoor air pollution on the respiratory health of children	Wood, kerosene stove	electric /gas stove	8
Azizi et al., 1995	Malaysia	7-12 years	359	57.4	To study the effects of indoor environmental factors on respiratory illness in children.	Wood, kerosene stove	No wood or kerosene stove	5
Bothwell et al., 2003	Northern Ireland	Under 12 years	2578	not reported	The prevalence of respiratory symptoms in children who lived in homes that used GFF heating was compared to their counterparts who lived in homes that contained other heating sources.	GFF Heating	No GFF heating	5
Carlsten et al., 2011	Canada	7 years	380	53.4	To evaluate the effect of combined early exposure to dog allergen plus indoor nitrogen dioxide or ETS on asthma or brochial hyperactivity in a high risk birth-cohort.	Gas stove	No gas stove	6

Casas et al., 2012	Germany	Under 10 years	4313	51.0	To assess the long-term impacts of exposure to gas cooking on the onset of asthma and respiratory symptoms.	Gas cooking ever	Gas cooking never	6
Daigler et al., 1991	USA	6 years	383	53.3	To investigate the possible association between home environmental air pollutants and their effects otitis media and asthma in children.	Wood	No wood burning	6
Dekker et al., 1991	Canada	5-8 years	10819	50.1	To investigate the influence of indoor air quality on respiratory health in Canadian homes.	Gas, oil, wood	electricity	7
Diette et al., 2007	USA	2-6 years	300	58.0	To study systematic differences in early life domestic exposures between inner city pre school children with and without asthma, we performed a study of indoor air pollutants and allergens.	Gas	electrcity	3
Dong et al., 2008	China	1-6 years	3945	50.1	To assess the effects of housing characteristics and home environmental factors on respiratory symptoms in children.	Coal cooking	Gas cooking	8
Dong et al., 2008	China	6-13 years	10784	50.4	To study the effects of housing characteristics, and other indoor environmental factors on the respiratory health of children.	Coal cooking	Gas cooking	8
xf et al.,1994	Nigeria	5.5 years	280	Not reported	To investigate the home environment of some asthmatic children in order to	Biomass smoke	No exposure to biomas	7

					identify such initiating, aggravating, or perpetuating factors.		s smoke	
Hessel et al., 2001	Canada	5-19 years	1035	Not reported	To understand host and indoor environmental factors associated with asthma.	Gas stove	No gas stove	8
Holscher et al., 2000	German y	5 – 14 years	2198	50.9	To assess whether gas cooking increases respiratory symptoms in children who do not exhibit signs of an acute respiratory infection	Gas stove	No gas stove	6
Infante-Rivard et al., 1993	Canada	3-4 years	914	54.9	To estimate the contribution to asthma incidence of chemical, physical, and biologic indoor environmental factors, as well as family history of asthma and past infections, after accounting for personal susceptability.	Kerosene, wood, gas, electricity	No kerose ne, wood, gas, electric ity	7
Kasznia-Kocot et al., 2010	Poland	13-15 years	1130	55.2	To ascertain the role of environmental factors in the development of adverse respiratory health outcomes.	Coal	No exposu re to coal	6
Kumar et al., 2015	India	7-15 years	3104	60.3	To examine the association between indoor air pollution and asthma in children in Delhi, India.	Biomass fuel	LPG fuel	4
Kumar et al., 2008	India		3456	59.2	To identify the effects of indoor air pollutants SO2 and NO2 and total suspended particulate matter generated from fuel used for cooking on	Biomass fuel	LPG fuel	7

					respiratory allergy in children			
Kurt et al., 2007	Turkey	6-15 years	25843	50.1	To evaluate prevalence and risk factors of asthma and allergic diseases in determining the prevalence of allergic diseases in Turkish school children.	Wood coal, biomass	Natura l gas	8
Lanphear et al., 2001	USA	Under 6 years	8257	49.5	To identify risk factors and estimate PAR of residential exposures for doctor diagnosed asthma in US children	Gas	No use of gas	7
Maier et al., 1997	USA	5-9 years	925	50	To describe the effect of indoor air pollution on the risk of asthma and undiagnosed asthma-like illness among US school children.	Gas, wood, kerosene	No use of gas, wood or kerose ne	7
McConnell et al., 2002	USA	9-6 years	3535	47.4	This study aimed to investigate the effect of indoor environment on incident asthma in adolescents.	Gas, wood	No gas, wood	7
Melsom et al., 2001	Nepal	11-17 years	247	63.0	To assess the importance of indoor environmental factors in Nepal	Biomass smoke	No biomas s smoke	6
Miao-Miao et al., 2013	China	3-7 years	6730	50.5	To evaluate the effect of ambient air pollution on respiratory health in kindergarten children.	Coal use	No coal use	9
Mortimer et al., 2017	Malawi	Under 5 years	10543	49.3	To compare the effects of a cleaner burning biomass-fuelled cookstove intervention to continuation of open fire cooking	Clean burning biomass cook stove	Open fire	

					on pneumonia in children.			
Mustapha et al., 2011	Nigeria	7-14 years	1397	Not reported	To test the hypothesis that ambient and indoor air pollution are risk factors for respiratory illness among school children.	Wood, coal, kerosene	Gas	7
Nguyen et al., 2010	USA	Under 18 years	1402	53.3	To further understand the burden of asthma among adults and children to identify health, socioeconomic, behavioural, and environmental factors associated with asthma.	Wood, gas	No wood, gas	6
Noorhassim et al., 1995	Malaysia	1-12 years	1007	51.4	To determine the prevalence of asthma and chronic respiratory symptoms; to investigate the associations between environmental factors namely exposure to cigarette smoke, use of mosquito coil, and use of wooden stove, and the prevalence of asthma and chronic respiratory symptoms.	Wood stove	No wood stove	3
Norbäck et al., 2019	China	3-6 years	39782	51.8	To study the indoor sources of indoor particulate matter, outdoor air pollution, and antibiotic use in relation to asthma, rhinitis, and eczema among children.	Coal, wood, biomass	Electricity	6
Oluwole et al., 2017	Nigeria	13.6 years	1690	51.7	To examine the effects of biomass smoke exposure on	Biomass fuel	No biomass fuel	7

					asthma prevalence in rural children in Nigeria.			
Oluwole et al., 2017	Nigeria				To extend the spectrum of environmental risk factors that may be contributing to towards increasing asthma morbidity, especially asthma symptoms severity in rural schoolchildren In Nigeria	Biomass fuel	No biomass fuel	7
Padhi et al., 2008	India	5-10 years	1505	Not reported	To investigate the association between the household use of biomass fuels for cooking and the prevelance of respiratory symptoms and diseases among children in rural India.	Biomass fuel	No biomass fuel	8
Peabody et al., 2005	China	6 months – 17 years	2285	52.1	To determine associations between individual health status as well as measures of indoor air-pollution sources, such as solid cooking fuels and cooking stoves.	Wood, crop residue, electricity,	coal	7
Qian et al., 2004	China	5-16 years	7058	49.5	To examine the respiratory health effects of residential coal use in 7058 school children	Coal exposure	No coal exposure	7
Qian et al., 2007	China	5-14 years	2517	100	To evaluate the effect of the diverse indoor air combustion sources on human respiratory health, examined associations between respiratory conditions and household factors.	Coal for heating and cooking	25^{th} percentile in the exposure to coal for heating and cooking	7

Qian et al., 2004	China				To examine associations between respiratory health outcomes and multiple household risk factors.	Coal for heating and cooking	1st percentile in the exposure to coal for heating and cooking	8
Rylance et al., 2019	Malawi	6-8 years	804	48.1	To assess the burden of chronic respiratory symptoms in children from households participating in the Cooking and Pneumonia study, a trial of cleaner burning biomass fuelled cookstoves.	Cleaner biomass fuelled cookstove	Traditional biomass fuelled cookstove	6
Schei et al., 2004	Guatamala	4-6 years	1058	48.0	To estimate the association of asthma with cooking on open wood fires, as preperation for a randomized control trial on the effects of indoor air pollution and child health.	Open fire	Plancha stove	6
Solis-Soto et al., 2013	Bolivia	9-15 years	2340	47.9	To assess the association between environmental factors and asthma, rhino conjunctivitis, and eczema symptoms in school-aged children from Bolivia.	Wood or coal	Gas or electricity	7
Tavernier et al,, 2006	UK	4-17 years	200	42.5	To investigate the indoor environment of English children.	LPG	No LPG fuel	6
van Miert et al., 2012	Belgium	15.2 years	744	45	To investigate whether wood fuel use was associated with respiratory diseases, sensitization to	Wood	No wood	6

					allergens, self reported symptoms.			
Volkmer et al., 1995	Australia	4-5 years	14124	Not reported	To investigate the relationship between indoor air quality and the prevelance of respiratory symptoms in children	Wood, natural gas	No wood, no natural gas	9
von Maffei et al., 2001	USA	Under 18	2464	Not reported	To examine relationships among urban and suburban rural residences, other environmental factors, familial factors and asthma for African American children in order to determine which factors are strongly associated with an increased risk of asthma in this group.	Gas, coal, wood, kerosene	No gas, coal, wood, or kerosene	4
von Mutius et al., 1996	Germany	9-11 years	1958	Not reported	To investigate the relation between different types of heating and the prevelance of atopic diseases, skin type reactivity, and bronchial hyper-responsivness.	Coal and wood	Gas, oil, central heating	6
Ware et al., 2014	USA	Under 18 years	561	53.6	To examine associations between household reporting of childhood respiratory conditions and household characteristics.	Oil and wood stove	Oil only	4
Wolff et al., 2012	Madagascar	7-14 years	1236	48.4	To establish the first epidemiological data concerning bronchial asthma in schoolchildren.	Charcoal, gas stove	Electric stove	9
Yang et al., 1997	Taiwan	6-12 years	4164	48.9	To determine whether indoor environmental	Gas cooking	No gas cooking	7

					factors affected respiratory symptoms in children.			
Zejda et al., 2003	Poland	14-16 years	663	49.3	To evaluate the cumulative incidence of physician diagnosed asthma over a period of 7 years and to determine its host and environmental risk factors in children.	Coal	No coal	6
Zheng et al., 2002	China	6-10 years	1209	58.7	To investigate the risk factors for childhood asthma.	Coal, gas	Electrc ity	6

Appendix Table 1B: Summary of studies investigating the association between HAP and childhood asthma

First Author and Year	Country	Participant age	n	% Of male	Objective	Exposure fuel	Comparator fuel
Acharya et al., 2015	Nepal	Under 5 years	4802	52.1	To assess the association between the use of solid fuel in the kitchen, and ARI among under 5 children in Nepal.	wood, animal dung, straw, shrubs, grass, crop residue, lignite, and charcoal	Electricity, LPG, biogas or natural gas
Adane et al., 2020	Ethiopia	Under 5 years	5830	51.7	To investigate the prevalence of childhood acute respiratory infection and associated factors in Northwest Ethiopia.	Cow dung, wood, straw, shrub Improved cookstove	Charcoal, traditional cookstove
Adane et al., 2020	Ethiopia	Under 3 years	5333	53.1	To investigate the child health effect of improved baking stove intervention compared with the continuation of the open burning stove.	Biomass fuelled improved bake stove	Biomass fuelled traditional bake stove
Adensanya et al., 2016	Nigeria	Under 5 years	28596	50.1	To investigate the effects of household fuel use and house ventilation on acute respiratory infection in children	Biomass, kerosene, charcoal indoors	Outdoor use of kerosene or charcoal
Admasie et al., 2018	Ethiopia	Under 5 years	1144	53	To investigate the effect of household fuel use and ventilation on acute respiratory infection in children.	Firewood, kerosene, charcoal, crop residue, dung cake, saw dust	Electricity
Akinyemi et al., 2018	Nigeria	Under 5 years	28950	50.4	To describe the trends in the prevalence and factors associated with ARI symptoms in children under 5 in Nigeria.	coal, ignite, charcoal, wood, kerosene, animal	electricity, liquefied petroleum gas, natural gas or biogas

						dung, straw, shrubs, and grass	
Aldous et al., 1996	USA	Under 1 year	936	Not given	To study the association between LRI and the home environment in children.	LPG	Electricity
Alemayehu et al., 2014	Ethiopia	Under 5 years	715	51.3	To investigate the association between household use of biomass fuels for cooking and acute respiratory infections in pre-school aged children.	Wood, dung or straw	LPG or electricity
Alemayehu et al., 2019	Ethiopia	Under 5 years	288	55.6	To assess risk factors for acute respiratory infection among under-five children attending public school in Southern Tigray, Ethiopia.	cow dung use	No cow dung use
Anteneh et al., 2020	Ethiopia	Under 5 years	1000 6	51.0	To determine regional variation and identify factors associated with acute respiratory infection.	Kerosene, charcoal, wood, straw, or animal dung	Electricity, or gas
Arlington et al., 2019	India	Under 6 months	1586	50.7	To assess the relationship between the exposure of solid fuels with the risk of ALRI in children.	Polluting solid fuel cook stove	No polluting solid fuel cook stove
Bates et al., 2013	Nepal	Under 3 years	917	56.7	To investigate the relationship of cook fuel type to ALRI in young children	Gas, kerosene, biomass, wood, coal	electricity
Bates et al., 2018	Nepal	Under 3 years	824	55.9	To examine the relationship of kitchen PM concentration to ALRI in households that use biomass and kerosene cooking fuels.	Gas, kerosene, biomass	electricity
Bautista et al., 2009	Dominic an Republic	Under 18 months	415	52.3	To investigate the effect of charcoal smoke exposure on the risk of acute upper respiratory and lower respiratory infection among children under 18 months of age in Santo Domingo, Dominican Republic.	Charcoal	Propane gas fuel
Bhat et al., 2012	India	Under 5 years	202	52.5	To determine the relationship of indoor air pollution with ALRTI in children under 5 years old.	Biomass fuel	LPG fuel

Bhat et al., 2013	India	Under 5 years	214	55.6	To study the association of socio-demographic, nutritional and environmental factors with ALRTI in children aged < 5 years.	Cooking fuels other than LPG	LPG
Broor et al., 2002	India	Under 5 years	512	70	To identify the modifiable risk factors for ALRTI in hospitalized children.	Cooking fuels other than LPG	LPG
Buchner et al., 2015	Benin, Burkina Faso, Cameroon, Ethiopia, Ghana, Guinea, Kenya, Madagascar, Mali, Malawi, Mozambique, Namibia, Niger, Senegal, Tanzaria, Uganda, Zambia, Zimbabwe	Under 5 years	56437	51.0	To assess solid fuel use for cooking as a risk factor for child ALRI in sub-Saharan Africa and to investigate the specific role of cooking location and stove ventilation on child ALRI.	Kerosene, coal, charcoal, wood, biomass	Electricity, LPG, biogas
Budge et al., 2014	Peru	Under 3 years	892	Not given	To determine the incidence of laboratory confirmed influenza in Andean children, describe the clinical characteristics of these infections, and identify risk factors for influenza acquisition.	Wood primary fuel	Wood not primary fuel
Budhathoki et al., 2020	Nepal	Under 5 years	15372	51.3	To assess the burden of pnuemonia attributable to HAP factors	kerosene, wood, straw, shrubs, grass, animal dung, coal and charcoal	LPG, biogas and natural gas
Bulkow et al., 2012	USA	Under 3 years	314	52.0	To evaluate risk factors for any LRTI hospitalization in cases compared with non-hospitalized control children	wood	No wood stove

Cardoso et al., 2013	Brazil	Under 5 years	321	Not given	To assess risk factors associated with hospital admission due to acute lower respiratory tract infection (ALRTI) in indigenous Guarani children<5 years of age in southern Brazil.	Wood, coal	Propane fuel
Cardoso et al., 2015	Brazil	Under 5 years	6081	51.4	To estimate the prevalence of pneumonia and evaluate associated factors among indigenous children under 5 years of age.	Wood stove, open fire	Propane fuel
Cerqueiro et al., 1990	Argentia	Under 5 years	1003	57.4	This paper is focussed on epidemiological risk factors in an effort to identify those most closely associated with ALRI	Bottled gas	No bottled gas
Chen et al., 2018	China	Under 18 years	1940	55	We examined the association of solid fuel use and paternal smoking on acute respiratory infections (ARI) in children focusing on child gender differences.	Coal, wood, charcoal	Electricity, kerosene, LPG
Coker et al., 2015	USA	Under 5 years	3240	Not given	Our objective is to investigate behaviors related to gas stove use, namely using them for heat and without ventilation, on the odds of pneumonia and cough in U.S. children	Gas stove with ventilation	Gas stove with no ventilation
Collings et al., 1990	Zimbabwe	10 months	744	53.9	To evaluate the significance of a number of factors that might contribute to the development of acute lower respiratory disease of early childhood.	Cooking with open fire	Cooking with paraffine, gas, electric stove
Dharmage et al., 1996	Sri Lanka	Under 5 years	200	Not given	Attempted to identify the determinants of acute lower respiratory tract infection among children younger than 5 years of age.	Kerosene oil, gas	No kerosene oil, gas
Esplugues et al., 2013	Spain	Under 1 year	2003	Not given	The aim of this study is to analyze the association between the use of gas cooking at home during pregnancy and respiratory problems in children during their first year of life	Gas	No gas
Etiler et al., 2002	Turkey	Under 1 year	204	50.1	The objective was study the incidence of ARI and its risk factors in Antalya, Turkey.	Biomass fuels	Central Heating

Fankunle et al., 2014	Nigeria	Under 5 years	220	55.5	To assess which environmental factors contribute to the acquisition of ARIs in children under 5 in Ibadan.	Firewood	No firewood
Foote et al., 2013	Kenya	Under 1 year	168	53.0	To assess the impact of upesi jiko on rates of respiratory disease in children.	Use of Upesi Jiko	No use of Upesi Jiko
Gurley et al., 2013	Banglade sh	Under 2 years	257	53.0	To estimate the effect of indoor exposure to particulate matter on the incidence of ALRI among children.	Biomass cooking fuel	Natural gas, electricity
Harerimana et al., 2016	Rwanda	Under 5 years	8599	50.7	To assess social, economic, and environmental factors associated acute lower respiratory tract infections in children under the age of 5 in Rwanda.	Wood, animal dung, straw, shrubs, grass	Electricity, LPG, natural gas, charcoal. coal
Hasan et al.,	Pakistan, Banglade sh and Nepal	Under 5 years	7760	Not given	The objective of this study was to compare the associations of sustainable household environmental practices with episodes of acute respiratory infection among children	Solid fuel	No solid fuel, or cooking outside the home
Holscher et al., 2000	Germany	5 – 14 years	2198	50.9	To assess whether gas cooking increases respiratory symptoms in children who do not exhibit signs of an acute respiratory infection	Gas stove	No gas stove
Islam et al., 2013	India	Under 5 years	370	68	To elicit the prevalence and risk factors associated with ARI among under-five children.	Wood, kerosene, cow dung	LPG
Janjua et al., 2012	Pakistan	Under 5 years	566	50.2	To evaluate the association etween the use of biomass fuel and acute respiratory infection (ARI) episodes in children aged <5years.	Biomass fuels	Fossil fuels
Karki et al., 2014	Nepal	Under 5 years	200	55.5	To identify the risk factors for pneumonia among children under the age of 5 in Nepal	Chulo with smoke exposure	Chulo without smoke exposure
Kashima et al., 2010	Indonesi a	Under 5 years	1524 2		To evaluate the effects of outdoor air pollution, taking into account indoor air pollution, in Indonesia	Coal, lignite, firewood, straw, dung	LPG, kerosene, electricity, biogas
Khan et al., 2018	Pakistan	Under 5 years	1104 0	50.95	To examine the effect of using polluting fuel for cooking on the respiratory health of children in Pakistan	solid fuel (wood, animal dung, charcoal, coal, shrubs) and kerosene	LPG, biogas, and electricity

Kilabuko et al., 2007	Tanzania	Under 5 years	5524	49.7	To test the hypothesis that the effect of biomass fuel use for cooking is higher than the effect of charcoal or kerosene on ARI among children in Tanzania.	biomass	Kerosene, charcoal
Lamichhane et al., 2017	India	Under 5 years	16157	52.0	To assess the impact of LPG and improved cook stove use on ARI in children younger than 5 years, including children in different population subgroups	Biomass, kerosene, coal, traditional cook stove	LPG, improved cook stove
Mahalanabis et al., 2002	India	Under 3 years	262	57.3	To evaluate the risk factors for childhood pneumonia with particular reference to indoor air pollution associated with solid fuel use for cooking using a case control study	Coal, wood, cow dung	No coal, wood, cow dung
Mir et al., 2018	India	Under 5 years	1644	53.8	To determine the magnitude of acute respiratory tract infections in children younger than 5 years in the rural areas of Kashmir valley, and to identify the various risk factors for ARI.	Firewood	LPG
Mishra et al., 2003	Zimbabwe	Under 5 years	3559	48.66	To investigate the association between household use of biomass fuels for cooking and acute respiratory infections in pre-school aged children (>5y) in Zimbabwe	Wood, dung, straw, charcoal, kerosene	LPG, natural gas or electricity
Morris et al., 1990	USA	Under 2 years	116	Not given	To test the hypothesis that the home use of wood burning stoves is an independent risk factor for LRTI in young children	Wood burning	No wood burning
Mortimer et al., 2017	Malawi	Under 5 years	10543	49.3	To compare the effects of a cleaner burning biomass-fuelled cookstove intervention to continuation of open fire cooking on pneumonia in children.	Clean burning biomass cook stove	Open fire
Murray et al., 2012	Bangladesh	Under 5 years	6979	48.58	To assess the association between cooking fuel, natural household ventilation and ALRI	Dung, wood, crop residue	Natural gas and other non-biomass
Naz et al., 2020	Pakistan	Under 5 years	9807	36.5	This study makes the attempt to examine the prevalence trend of pneumonia among under 5 children in Pakistan in association with IAP related factors.	kerosene, wood, straw, shrubs, grass, animal dung, coal, charcoal,	electricity, LPG, biogas, natural gas

						agricultural residuals, and others	
Ngocho et al., 2019	Tanzania	Under 5 years	463	58.9	To identify the modifiable risk factors for community-acquired pneumonia (CAP) in children under 5 years of age in a vaccinated population.	Biomass, firewood, charcoal, kerosene	Gas, electricity
Patel et al., 2019	India	Under 5 years	9323 41`	52.4	This study examines the use of cooking fuel sources and their association with acute respiratory infections in children aged 0-59 months.	Firewood, crop residue, dung cake, coal, lignite, charcoal, kerosene	LPG, electricity
Praygod et al., 2016	Tanzania	Under 5 years	117	50.4	To determine the risk factors of severe pneumonia in children aged under 5years of age in Mwanza, Tanzania.	Firewood, wood, charcoal	LPG, electricity
Ramani et al., 2016	India	Under 5 years	400	44.75	determining ARI morbidity among under-fives in urban slums, and to study the epidemiological factors responsible for same	Firewood, LPG	No firewood, LPG
Rana et al., 2019	Afghanis tan	Under 5 years	2756 5	51.7	We examined the association between solid fuel use and acute respiratory infection among under 5 years old in Afghanistan	Solid fuel use	Non-solid fuel use
Ranathunga. et al., 2019	Sri Lanka	Under 5 years	260	54.1	To determine the association between household air pollution due to combustion of biomass fuel in Sri Lankan households and self-reported respiratory symptoms in children under 5 years.	Biomass, kerosene	LPG or electricity
Rey-Ares et al., 2016	Argentin a and Chile	Under 5 years	1074	50.7	The main objective of this study was to evaluate the association between HAP with LRTI in children younger than 5 years old and adverse pregnancy outcomes.	Biomass fuel for cooking	No biomass fuel exposure
Robin et al., 2016	USA	Under 2 years	90	60	To examine the association between ALRI with exposure to domestic smoke among Navajo children seen at the public health service Indian hospital.	Wood	Gas, electricity
Rumchev et al., 2016	Myanma r	Under 6 years	80		To determine the prevalence of childhood respiratory symptoms in	Biomass	No biomass

					association with the use of biomass for cooking		
Sanbata et al., 2014	Ethiopia	Under 5 years	422	67.5	Examines the association between use of biomass fuels and acute respiratory infections in children	Wood, dung, charcoal. Biomass, kerosene, urban residue	LPG and electricity
Savitha et al., 2007	India	Under 5 years	208	58.17	To identify various modifiable risk factors for acute lower respiratory tract infections in children aged 1m - 5y	Fire wood, cow dung, kerosene	LPG
Shah et al., 1994	India	Under 5 years	400	57	To identify the risk factors for severe ARI, or pneumonia in children younger than the age of 5 in South Kerala.	Smoke producing stove	Non-smoke producing stove
Sharma et al., 2013	India	Under 5 years	500	51.4	To determine the prevalence of ARI and its risk factors among under five children in urban and rural areas of Kancheepuram district, South India	Smokey fuel	Smokeless fuel
Smith et al., 2011	Guatema la	Under 18 months	518		To investigate whether an intervention to lower indoor wood emissions would reduce pnuemonia in children	Open wood fires	Wood stove with chimney
Sunyer et al., 2003	Spain	Under 1 year	1611	52.7	To assess the association between indoor NO2 and LRTI during the first years of life in a multicentre prospective cohort study	Gas	No use of gas
Suryadhi et al., 2019	Indonesi a	4.8 years	3684 2	52.0	To evaluate the effect of combined exposure to HAP from solid fuel and ETS on child health outcomes in Indonesia, where indoor air pollution from both sources is more common than in developed nations or in African nations.	Solid fuel use	No solid fuel use
Taylor et al., 2012	Sierra Leone	Under 5 years	520	51.4	This study investigated the prevalence of ARI potentially caused by smoke from wood and charcoal stoves in Western Sierra Leonne.	Wood fuel	Charcoal fuel
Tazinya et al., 2018	Cameroo n	Under 5 years	512	56.8	This study aimed at determining the proportion of acute respiratory infections and the associated risk factors in children under 5 years	Wood smoke	No wood smoke

					visiting the Bamenda Regional Hospital in Cameroon.		
Tielsch et al., 2009	India	Under 6 months	11728	Not given	To asssess the association between the exposure to biomass fuel sources, tobacco smoke in the home and adverse health outcomes in early infancy.	Wood or dung	No exposure to wood or dung
Tin et al., 2016	New Zealand	Under 5 years	6112		This New Zealand study investigated current exposures to specific risk factors in the home during the first 5 years of life and provided evidence on the links between the home environment and childhood ARI hospitalization.	Wood, electricity, gas	No wood, electricity, gas
Tumwesigire et al., 1995	Uganda	Under 5 years	152	53.3	to explore relationships between environmental household conditions and the presence or absence of acute respiratory infections.	Wood, charcoal	Gas, electricity
Upadhyay et al., 2015	India	Under 6 years	3961	53.5	This study estimated the impact of household use of solid fuels for cooking on LRTI in children in India.	Wood, charcoal, coal, and cow-dung	Electricity, gas and kerosene
Victora et al., 1994	Brazil	Under 2 years	1032	54.1	To investigate risk factors for pneumonia for infants <2 years of age	Wood, open-air fires	Non-smoke producing fuels
Wafula et al., 2000	Kenya	Under 5 years	648	Not given	To estimate the effect of improved stoves on the prevalence of ARI and conjunctivitis among children aged below five years and women aged between 15 and 60 years.	Improved Stove	Traditional 3 stone stove
Wang et al., 2013	China	Under 5 years	4618	53.7	In order to evaluate the prevalence of childhood asthma, allergic diseases and pneumonia in Urumqi City, China, as well as its associations with housing and home characteristics	Coal, wood	Gas, electricity
Ware et al., 2014	USA	Under 18 years	561	53.6	To examine associations between household reporting of childhood respiratory conditions and household characteristics related to air pollution in Native indian communities.	Wood stove	Fuel oil only
Wayse et al., 2004	India	Under 5 years	150	59.3	To determine whether subclinical vitamin D deficiency in Indian children under 5 y of age is a risk	Biomass	LPG

					factor for severe acute lower respiratory infection (ALRI).		
Wichmann et al., 2006	South Africa	Under 5 years	4679	50.4	To explore the connection between polluting fuel use for cooking and heating with childhood (<5y) with childhood ALRIs in South Africa.	wood, dung, paraffin, charcoal in combination with LPG	LPG

Appendix Table 2B: Summary of studies investigating the association between HAP and childhood ALRI

First Author, year	Title	Journal	Region of Study	Type of Study	Objective of Study	Selected Outcomes	Risk of Bias Assessment (NOS scale)
*Azizi & Henry, 1990 [14]	Effects of indoor air pollution on lung function of primary school children in Kuala Lumpur	Pediatric Pulmonology	Malaysia	Cross-sectional study	We examined the relationships between exposure to indoor environmental factors, namely mosquito repellents, environmental tobacco smoke, and cooking stoves, and levels of lung function in Malaysian children.	PPV, and mean values of FVC, $FEV_{1,}$ FEF_{25-75} and PEFR	7
*Da Silva et al., 2012 [6]	Impaired lung function in individuals chronically exposed to biomass combustion	Environmental Research	Brazil	Cross Sectional study	To evaluate the respiratory effects of biomass combustion and compare the results with those of individuals from the same community in Brazil using liquefied petroleum gas	Mean values a FEV_1/FVC and precent predicted values of $FEV_{1.}$	7

*Gharaibeh, 1995 [13]	Effects of indoor air pollution on lung function of primary school children in Jordan	Annals of Tropical Paediatrics	Jordan	Cross Sectional study	To determine the effect of environmental exposures to unvented cook stoves on respiratory function.	mean values of spirometric measures - FVC, FEV1, FEF25-75, and PEFR	6
*Heinzerling et al., 2016 [9]	Lung function in woodsmoke-exposed Guatemalan children following a chimney stove intervention	Thorax	Guatemala	Prospective cohort study	To determine the effect of early childhood HAP exposure on growth of lung function with a chimney stove intervention	PPV, mean values of spirometric measures - FEV_1, FVC, FEV_1/ FVC, and FEF_{25-75} and PEF	8
*Jedrychowski et al., 2005 [16]	Effect of indoor air quality in the postnatal period on lung function in pre-adolescent children: A retrospective cohort study in Poland	Journal of the Royal Institute of Public Health	Poland	Cohort Study	The purpose of this study was to determine the association between level of lung function in pre-adolescence and indoor air quality in the postnatal period.	Mean values and regression coefficients of spirometric measures – FVC, and FEV_1.	
*Oluwole et al., 2013 [15]	Effect of stove intervention on household air pollution and the respiratory health of women and children in rural Nigeria	Global Journal of Health Science	Nigeria	Cross sectional study	The objective of the study was to investigate the extent of household air pollution from biomass fuels and the effectiveness of stove intervention to improve indoor air quality, exposure-related health problems,	PPV, mean values of spirometric measures - FVC, FEV_1, FEF_{25-75}, and PEFR	6

					and lung function		
*Padhi & Padhy, 2008 [12]	Domestic fuels, indoor air pollution, and children's health: The case of rural India	Annals of the New York Academy of Sciences	India	Cross sectional study	To investigate the association between household use of biomass	mean values of PEF, FVC, FEV_1, FEV_1/FVC, $FEF_{25-75\%}$,	7
*Rennert et al., 2015 [11]	The effects of smokeless cookstoves on peak expiratory flow rates in rural Honduras	Journal of Public Health	Honduras	Cross Sectional study	To assess the effects of improved stove designs on the peak expiratory flow rates and respiratory health of community members	Mean values of spirometric measurements - PEFR	9
*Rinne et al., 2006 [8]	Relationship of pulmonary function among women and children to indoor air pollution from biomass use in rural Ecuador	Respiratory Medicine	Ecuador	Cross Sectional study	To examine the impact of biomass fuel use on pulmonary function among women and children in a rural Ecuadorian community.	Mean value of spirometric measures – FVC, FEV_1, FEV_1/FVC, FEF_{25-75}	7
*Roy et al., 2012 [7]	Indoor air pollution and lung function growth among children in four cities in China	Indoor Air	China	Prospective cohort study	The current analyses focused on examining the relationship of children's lung function growth with household coal burning and household ventilation practices.	Mean value of spirometric measures – FVC, FEV_1, and FEV_1/FVC	7
*Thacher et al., 2013 [17]	Biomass fuel use and the risk of asthma in Nigerian children	Respiratory Medicine	Nigeria	Cross Sectional study	We studied the relationship of biomass fuel use with asthma symptoms and lung function in Nigerian children.	PPV, mean values of spirometric measures – FEV_6, FEV_1, FEV_1/ FEV_6	6

Appendix Table 3B: Summary of studies investigating the association between HAP and childhood Lung function

Appendix C

Source	Selection				Comparability based on design and analysis	Outcome		Total
	Representativeness of the sample	Sample size	Non-respondents	Ascertainment of exposure to HAP		Assessment of outcome	Statistical test	
Azizi & Henry, 1990 [14]	+	+	-	-	++	++	+	7
Gharaibeh, 1995 [13]	+	+	-	+	+	++	+	6
Oluwole et al., 2013 [15]	+	-	-	+	+	++	+	6
Padhi & Padhy, 2008 [12]	+	+	-	-	++	++	+	7
Rinne et al., 2006 [8]	+	+	-	-	++	++	+	7
Thacher et al., 2013 [17]	+	+	-	+	-	++	+	6
Da Silva et al., 2012 [6]	+	+	-	+	++	+	+	7
Rennert et al., 2015 [11]	+	+	-	+	++	++	+	9

Appendix Table 1C: Risk of Bias analysis using the modified Newcastle Ottawa Scale for cross-sectional studies examining the association between HAP and lung function

Source	Selection				Comparability	Outcome			Total
	Representativeness of the exposed cohort	Selection of non-exposed	Ascertainment of exposure to HAP	Demonstration of absence of outcome at the start		Assessment of outcome	Length of follow up	Adequacy of follow up	
Heinzerling et al., 2016	+	+	+	-	++	+	+	+	8
Roy et al., 2012	+	+	-	-	++	+	+	+	7
AJedrychowski et al., 2005	+	-	+	+	++	+	+	+	9

Appendix Table 2C: Risk of Bias analysis using the Newcastle Ottawa Scale for cohort studies examining the association between HAP and lung function

	Selection				Comparability	Outcome		Total
First author and year	**Representativeness of the sample**	**Sample size**	**Non-respondents**	**Ascertainment of the exposure**	**Confounding factors controlled**	**Assessment of outcome**	**Statistical test**	**Total**
Azizi et al., 1991	1	1	0	2	2	1	1	8
Adane et al., 2020	1	1	1	1	2	1	1	8
Adesanya et al., 2016	1	1	1	1	2	1	1	8
Alemayehu et al., 2014	1	1	1	1	2	1	1	8
Anteneh et al., 2020	1	1	0	1	2	1	1	7
Bothwell et al., 2003	1	1	0	1	0	1	1	5
Buchner et al., 2015	1	1	0	1	2	1	1	7
Budhathoki et al., 2020	1	1	0	1	2	1	1	7
Cardoso et al., 2015	1	1	1	1	2	1	1	8
Chen et al., 2018	1	1	0	1	0	1	1	5
Coker et al., 2015	1	1	1	1	2	1	1	8
Collings et al., 1990	0	1	0	0	0	2	1	4
Dekker et al., 1991	1	1	0	2	1	1	1	7
Dong et al., 2008	1	1	0	2	2	1	1	8
Hasan et al.,								
Harerimana et al., 2016	1	1	1	1	2	1	1	8
Holscher et al., 2000	1	1	0	0	2	1	1	6
Islam et al., 2013	1	1	0	1	2	1	1	7
Janjua et al., 2012	1	1	1	1	2	1	1	8
Kashima et al., 2010	1	1	0	0	2	1	1	6
Kasznia-Kocot et al., 2010	1	1	0	1	1	1	1	6
Kumar et al., 2015	1	1	0	1	0	1	0	4
Khan et al., 2018	1	1	1	1	2	1	1	8
Kilabuko et al., 2007	1	1	0	2	2	1	**1**	8
Kumar et al., 2008	1	1	0	1	2	1	1	7
Kurt et al., 2001	1	1	0	2	2	1	1	8
Lanphear et al., 2001	1	1	0	1	2	1	1	7
Lamichhane et al., 2017	1	1	0	1	2	1	1	7
Mir et al., 2018	1	1	0	0	1	1	1	5
Mishra et al., 2003	1	1	1	1	2	1	1	8

Maier et al., 1997	0	1	0	2	2	1	1	7
Miao-Miao et al., 2013	1	1	1	2	2	1	1	9
Mustapha et al., 2011	1	1	0	1	2	1	1	7
Noorhassim et al., 1995	1	1	0	0	0	1	0	3
Naz et al., 2020	1	1	0	1	1	1	1	6
Nörback et al., 2019	1	1	0	0	2	1	1	7
Oluwole et al., 2017	1	1	0	1	2	1	1	7
Oluwole et al., 2017	1	1	0	1	2	1	1	7
Patel et al., 2013	1	1	0	1	2	1	1	7
Patel et al., 2019	0	1	0	0	2	1	1	5
Padhi et al., 2008	1	1	0	2	2	1	1	8
Peabody et al., 2005	1	1	0	1	2	1	1	7
Qian et al., 2004	0	1	1	1	2	1	1	7
Qian et al., 2007	1	1	1	1	2	1	0	7
Qian et al., 2004	1	1	1	1	2	1	1	8
Rana et al., 2019	1	1	1	1	2	1	1	8
Rumchev et al., 2016	1	0	0	1	2	1	1	6
Rylance et al., 2019	0	1	1	0	2	1	1	6
Sanbata et al., 2014	1	1	0	2	2	1	1	8
Schei et al., 2004	1	1	0	0	2	1	1	6
Sharma et al., 2013	1	1	0	0	0	1	0	3
Solis-Soto et al., 2013	1	1	0	1	2	1	1	7
Suryadhi et al., 2019	1	1	1	2	2	1	1	9
Taylor et al., 2012	1	1	0	0	1	1	1	5
Tazinya et al., 2018	0	1	0	1	2	1	1	6
Van Miert et al., 2012	0	1	0	1	2	1	1	6
Volkmer et al., 1995	1	1	1	2	2	1	1	9
Von Maffei et al., 2001	1	1	0	1	0	1	0	4
Von Mutius et al., 1996	1	1	0	0	2	1	1	6
Ware et al., 2014	1	1	0	0	0	1	1	4
Wang et al., 2013	1	1	0	1	2	1	1	7
Wichmann et al., 2006	1	1	1	0	2	1	1	7
Wolff et al., 2012	1	1	1	2	2	1	1	9
Yang et al., 1997	1	1	1	0	2	1	1	7

Appendix Table 3C: Risk of Bias analysis using the Newcastle Ottawa Scale of cross-sectional studies examining the association between HAP and Asthma, ALRI

	Selection				Comparability	Outcome			
		Selection of non-exposed cohort	**Ascertainment of exposure**	**Outcome does not present at the start of the study**	**Confounding factors controlled**	**Assessment of outcome**	**Follow-up length**	**Loss to follow-up rate**	**Total**
Aldous et al., 1996	0	1	1	1	2	1	1	1	8
Arlington et al., 2019	1	1	0	0	1	0	1	1	5
Bautista et al., 2009	1	1	1	0	2	1	1	1	8
Budge et al., 2014	1	1	1	0	2	1	1	0	7
Casas et al., 2012	1	1	0	1	2	0	1	0	6
Esplugues et al., 2013	1	1	1	1	2	0	1	0	7
Etiler et al., 2002	1	1	1	1	0	0	1	0	5
Foote et al., 2013	1	1							
McConnell et al., 2002	1	1	1	1	2	0	1	0	7
Ramani et al., 2016	1	1	1	0	0	0	1	0	4
Ranathunga et al., 2019	1	1	0	0	2	0	1	0	5
Rey-Ares et al., 2016	1	1	1	0	2	0	1	1	7
Sunyer et al., 2003	1	1	1	1	2	0	1	1	8
Tielsch et al., 2009	1	1	1	1	2	0	1	0	**7**
Tin et al., 2016	1	1	1	1	2	1	1	0	**8**
Upadhyay et al., 2015	1	1	1	0	1	0	1	0	**5**
Zejda et al., 2003	0	1	0	1	2	1	1	0	**6**

Appendix Table 4C: Risk of Bias analysis using the Newcastle Ottawa Scale of case-control and cohort studies examining the association between HAP and Asthma, ALRI