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Adverse birth outcomes associated with household air pollution from unclean cooking fuels in low- and middle-income countries: A systematic review

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ABSTRACT

Approximately 3.8 billion people in low- and middle-income countries use unclean fuels as a source of primary cooking fuel as well as for heating. For pregnant women, the toxic chemicals produced by combustion of unclean fuels not only affect women's health directly, but particulate matter and carbon monoxide are absorbed in maternal blood and cross the placental barrier impairing fetal tissue growth. PRISMA 2009 guidelines were used for this systematic review. The inclusion criteria were quantitative, peer reviewed journal articles published within a date range of May 1, 2013–June 12, 2021 examining birth outcomes related to household air pollution from type of cooking fuel in low- and middle-income countries. The quality of available evidence was evaluated using the Office of Health Assessment and Translation (OHAT) risk of bias rating tool. Of the 553 studies screened, 23 satisfied the inclusion criteria. Of the studies that met the inclusion criteria, 14 were cross-sectional, 5 cohort, 1 case-control and 3 randomized control trials conducted across 15 different countries. A range of birth outcomes are reported across studies including birthweight (19), small for gestational age (6), spontaneous abortion (3), preterm birth (6), stillbirth (7) and neonatal mortality (6). The reviewed studies presented evidence for an increased risk of low birth weight (LBW), preterm birth (PTB), small for gestational age (SGA), stillbirth, neonatal mortality and reduction in birthweight with solid fuel and kerosene use compared to cleaner fuels like gas and LPG. Systematically reviewing the evidence and risk of bias ratings illuminated several gaps in the current literature related to exposure assessment, outcome measurement and adequacy of adjustment for confounding.

1. Introduction

Approximately 3.8 billion people in low- and middle-income countries (LMICs) use unclean fuel for cooking and in 2019 close to 2.3 million people died prematurely due to illnesses attributable to household air pollution (HAP). The most recent World Health Organization (WHO) guidelines include recommendations not only against the use of solid household fuels such as coal, charcoal, wood and dung but also kerosene, which are considered highly-polluting (WHO, 2014). Cleaner burning, less polluting cooking fuels are liquid petroleum gas (LPG), gases such as biogas/natural gas, electricity and solar.· The combustion of unclean fuels during the heating process releases harmful chemicals such as carbon monoxide and particulate matter that can result in HAP levels many times higher than acceptable air quality levels (Smith, 1993; WHO, 2007, 2021). According to the Institute for Health Metrics and Evaluation (IHME), HAP is the 8th most important contributor to the overall global disease burden (IHME, 2018). These health impacts include childhood pneumonia, cardiovascular diseases, chronic obstructive respiratory disease, lung cancer and cataracts (Dherani et al., 2008; Kurmi et al., 2012; Kurmi et al., 2012; Kurmi et al., 2010;

Abbreviations: BMI, body mass index; BW, birthweight; CO, carbon monoxide; HAP, Household Air Pollution; IHME, Institute for Health Metrics and Evaluation; IUGR, Intrauterine Growth Restriction; LBW, low birth weight; LMICs, low- and middle-income countries; LPG, liquefied petroleum gas; OHAT, Office of Health Assessment and Translation; PM, particulate matter; PTB, preterm birth; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; SAB, spontaneous abortion; SDGs, Sustainable Development Goals; SGA, small for gestational age; WHO, World Health Organization.

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Smith et al., 2011; Smith et al., 2004). A recent impact assessment on the health burden associated with exposure to household air pollution estimated that in 2017, HAP was associated with 1.8 million deaths and 60.9 million disability adjusted life years (DALYs) globally (Lee et al., 2020).

The burden of adverse birth outcomes disproportionally occurs in LMICs where 190 million (89%) of the estimated 213 million pregnancies worldwide occur annually (McDonald et al., 2020; Sedgh et al., 2014). Approximately 60% of global preterm births occur in sub-Saharan African and south Asia each year (Blencowe et al., 2012; McDonald et al., 2020). This translates to about 12% of babies born in LMICs are preterm compared to 9% in higher-income countries (WHO, 2018). In 2015, 1 in every 7 newborns was born with low birthweight (LBW, birthweight <2500 g) amounting to 20.5 million LBW babies globally (UNICEF, 2019). The prevalence of LBW in 2015 varied from 7.2% in more developed regions to 13.7% in Africa and 17.3% in Asia (UNICEF, 2019). Every day there are roughly 7,000 newborn deaths and 5,000 stillbirths, 98% of which occur in LMICs (Gibson et al., 2021; The Lancet, 2016). These estimates may underestimate actual prevalence of adverse outcomes since many babies are not weighed at birth and births may occur at home or in small clinics without official reporting (Marete et al., 2020; WHO, 2014). Women are particularly vulnerable to high exposure levels of HAP since they are primarily responsible for cooking and tending to the kitchen; children under 5 also have a high exposure and disease risk since they spend much of their time with their mother (Amegah and Jaakkola, 2016; Burnett et al., 2014; Smith et al., 2014). During pregnancy, toxic chemicals produced by unclean fuel combustion adversely affect the health of both the exposed mother and fetus. Particulate matter and carbon monoxide, two important by-products of incomplete combustion, are absorbed in maternal blood and cross the placental barrier impairing fetal tissue growth through hypoxia/oxidative stress (Li et al., 2003; Pope et al., 2010).

The body of research connecting the role of household air pollution from unclean fuel use with adverse pregnancy outcomes in low- and middle-income countries is growing. Ghosh et al. (2021) estimated a global population-weighted mean lowering of 89 g of birthweight and 3.4 weeks of gestational age as well as 15.6% of all LBW and 35.7% of all PTB infants attributable to ambient and HAP $PM_{2.5}$ in 2019. A systematic review and meta-analysis conducted by Pope et al. (2010) demonstrated household solid fuel use is associated with an increase in the relative risk of LBW and stillbirth. The systematic review and meta-analysis by Amegah et al. (2014) evaluated 19 articles published before 2014 on the association between HAP and expanded pregnancy outcomes to birthweight, stillbirth, preterm birth, intrauterine growth restriction and miscarriage. The analysis found that household combustion from solid fuels resulted in a statistically significant mean reduction in birthweight of 86.4 g, a 35% increased risk of LBW and 29% increased risk of stillbirth. The authors also noted methodological limitations in most of the selected studies particularly regarding direct exposure measurement and called for future research with higher quality evidence on a broader range of adverse pregnancy outcomes. A comprehensive systematic review, meta-analysis and burden of estimation study by Lee et al. (2020) also limited pregnancy outcomes to birthweight and stillbirth. Specifically, the pooled relative risk was 1.36 for low birthweight, 1.22 for stillbirth and a 149 g average reduction of birthweight with use of polluting fuels. Since the publication of Amegah et al. (2014) seven years ago, an expanding field of HAP research has focused on a range of adverse birth outcomes, including three recently published randomized stove intervention trials, necessitating a current review of the new evidence.

The use of unclean cooking fuels remains widespread despite mounting evidence of harmful health effects (Amegah and Jaakkola, 2016). In 2018, the global population without access to clean cooking fuels and technologies was 2.8 billion and nineteen countries accounting for approximately 80% were in Africa. While trends indicate the proportion of the population using unclean fuels is declining in Asia, southern Africa and most regions of South America; several countries in sub-Saharan Africa are exhibiting net increases in the proportion of the population exposed to HAP due to population growth and reliance on unclean fuel (IHME, 2018). To combat these trends, in 2015 all United Nation Member States adopted the 2030 agenda of 17 Sustainable Development Goals (SDGs). SDG 3, 7 and 11 address indicators of disease burden from household and ambient air pollution (Amegah and Jaakkola, 2016; UN, 2015). See Box 1.

1.1. Objectives and rationale

This systematic review of the literature updates the evidence by asking: is household air pollution from unclean cooking fuels associated with adverse birth outcomes in low- and middle-income countries? The aims of this systematic review of international articles are 1) to appraise research evidence of an association between household air pollution from unclean cooking fuel and adverse birth outcomes 2) to evaluate the quality of available evidence using the Office of Health Assessment and Translation (OHAT) risk of bias rating tool, and 3) to identify knowledge gaps to inform future research. Since the last systematic review search ended April 2013, this systematic review synthesizes the current research from 2013 to 2021 (Amegah et al., 2014).

2. Methods

2.1. Literature search

We organized this systematic review using the 2009 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement guidelines (Moher et al., 2009). The design details, analysis and inclusion criteria were preregistered on the International prospective register of systematic reviews. (PROSPERO Registration number: CRD42020152333).

Our inclusion criteria were peer reviewed journal articles published within a date range of May 1, 2013–June 12, 2021 examining birth outcomes related to household air pollution from unclean cooking fuel in low- and middle-income countries. The PECO for the study as defined by Morgan et al. (2018) includes: Participants were pregnant women in low- and middle-income countries; Exposure was household air pollution from unclean cooking fuels; Comparator was the household air pollution from clean cooking fuel; Outcome was adverse birth outcomes. Low- and middle-income countries (Gross National Income per capita <$1,046 to < $4,095 respectively) were chosen since unclean cooking fuels is more likely to be used in these countries (World Bank, 2021). Primary and secondary data analysis studies that investigated the association between household air pollution as a primary exposure and the risk of adverse birth outcomes in the human population were included in the review. Language was restricted to studies written in English and Spanish due to evaluator language ability. Studies were excluded if they addressed topics other than household air pollution from cooking fuels, such as ambient air pollution, used a non-quantitative study design, or evaluated outcomes not related to pregnancy, childbirth or the neonatal period. Studies only available as posters or abstracts were also excluded.

Studies were identified using search strategies within PubMed, EMBASE, CINAHL and Web of Science databases. In the most recent systematic review on HAP and adverse pregnancy outcomes by Amegah et al. (2014) publication dates were constrained to database inception to April 30, 2013; therefore our search, which updates the previous systematic review, included publication dates of May 1, 2013–June 12, 2021. Medical Subject Heading (MeSH) search terms and free text words were systematically combined to identify relevant studies. The search strategy was adapted to each database after adding Boolean operators such as “AND/OR”. Search terms are presented in Table 1. After compiling the results from the database searches, the author hand searched for additional relevant articles using references from sourced studies. The last hand search was done June 13, 2021. The full search strategy is included in Supplement #1.

Box 1
Sustainable Development Goals and Targets

SDG 3: Ensure healthy lives and promote well-being for all at all ages.
Target 3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination.
SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all.
Target 7.1: By 2030, ensure universal access to affordable, reliable and modern energy services.
SDG 11: Make cities and human settlements inclusive, safe, resilient and sustainable.
Target 11.6: By 2030, reduce the adverse per capital environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.

Table 1
Search terms.

Exposure		Outcomes
MeSH terms	Free text words	MeSH terms
“Air Pollution, Indoor"	“household air pollution"	“Pregnancy outcome"
Biofuels	“household fuel"	“Pregnancy outcome/adverse effects"
Biomass	“domestic fuel"	“Birth Weight"
Coal	“cooking fuel"	“Infant, Low Birth Weight"
Wood	“cooking smoke"	“Premature Birth"
Kerosene	“solid fuel"	“Infant, Premature"
Cooking	firewood	“Gestational Age"
	“crop residue"	“Infant, Small for Gestational Age"
	“biomass fuel"	Stillbirth
	“biomass smoke"	“Fetal Mortality"
	“wood fuel"	“Fetal Death"
	“wood smoke"	“Perinatal Mortality"
	“charcoal smoke"	“Perinatal Death"
	“unclean fuel"	“Infant Mortality"
		“Abortion, Spontaneous"
		“Maternal Mortality"

2.2. Study selection

Relevant results were compiled in EndNote 20 and scanned for duplicates. The eligible studies were then organized in the Cochrane Review endorsed online software program Covidence systematic review software. Screening and eligibility assessment were performed by two independent investigators (AY and RJL). First, potential studies were screened by title and abstract using the eligibility criteria. Second, studies were eliminated if they did not address household air pollution or pregnancy, and/or fell outside publication dates. The remaining articles that met inclusion criteria were screened by full text assessment using eligibility criteria with exclusion based on study design and outcome measures. If any disagreements occurred, the two reviewers made joint decisions after discussion of the inclusion eligibility.

2.3. Data collection and items

Data were extracted from included studies that were evaluated independently by two investigators (AY and LMT) through full-text review and Covidence software. Extracted variables included author, setting, study design, sample size, measurement and assessment of exposure and outcomes, and covariates used in adjusted models. Adverse birth outcomes extracted for this review are defined as low birth weight (<2500 g), birthweight, small for gestational age (birthweight<10th percentile), spontaneous abortion (<20 weeks gestation), preterm birth (<37 weeks gestation), stillbirth (≥20 weeks gestation) and neonatal mortality (birth to 28 days). We organized data from each study into three tables: 1) study characteristics, 2) summaries of study results of adverse pregnancy outcomes associated with cooking fuel and, 3) an assessment of risk of bias.

Data were summarized in table form to include birth outcomes related to cooking fuel type. Outcomes were then extracted and reported in adjusted odds (aOR), risk ratios (aRR), hazard ratios (aHR) or posterior means (p.mean) of low birth weight, small for gestational age, spontaneous abortion, preterm birth, stillbirth and neonatal mortality. Birthweight was reported as an adjusted mean difference in grams or kilograms. If data were not adjusted, unadjusted values were presented. Due to the heterogeneity of exposure and outcome reporting, a meta-analysis of findings could not be performed, instead findings were synthesized using a narrative approach into text and tables. The included articles were placed in alphabetical order in Tables 2 and 3. Risk of bias ratings for each study are presented in Table 4. Figs. 3–5 present study design, exposure and outcome assessment measures for grouped outcomes.

2.4. Risk of bias in individual studies

The risk of bias and quality assessment of the included articles was determined by three reviewers (AY, LMT, RJL) utilizing the Office of Health Assessment and Translation (OHAT) tool created by the National Toxicology Program (OHAT, 2015). The OHAT tool was created to evaluate individual study risk of bias or internal validity for human and non-human animal studies. The framework is structured with 11 risk of bias questions or domains with each question applicable for 1 to 6 study design types (animal or human controlled trial, cohort, case-control, cross-sectional, case series). The questions are grouped under 6 types of bias domains: selection, confounding, performance, attrition/exclusion, detection and selective reporting. Finally the questions are rated by selecting among 4 possible answer format options including:

- Definitely Low risk of bias: There is direct evidence of low risk of bias practices
- Probably Low risk of bias: There is indirect evidence of low risk of bias practices OR it is deemed that deviations from low risk-of -bias practices for these criteria during the study would not appreciably bias results, including consideration of direction and magnitude of bias.
- Probably High risk of bias: There is indirect evidence of high risk of bias practices OR there is insufficient information (not reported or “NR”) provided about relevant risk of bias practices
- Definitely High risk of bias: There is direct evidence of high risk of bias practices

A conservative approach was taken for studies with insufficient information to judge risk of bias for an individual question by defaulting to the more conservative category as suggested by the OHAT tool instructions.

3. Results

3.1. Study selection

The literature search identified 553 articles for review. During the selection process, 530 articles were excluded either because they were duplicates (n = 122), the abstract indicated they did not meet the screening criteria (n = 331), or full text review indicated they did not meet inclusion criteria (n = 77). A total of 23 studies were included in the final quantitative synthesis. The PRISMA flow diagram of study selection is depicted in Fig. 1.

3.2. Study characteristics

Twenty-three studies were included in this review with full study characteristics presented in Table 2 where they are categorized in alphabetical order and labeled with references 1–23. The selected studies employed various research designs. Fourteen of the studies used cross-sectional designs [2, 4–7, 9, 11–14, 17–19, 21] of which nine analyzed national demographic data such as Demographic and Health Surveys (DHS) [4–7, 11, 12, 14, 17, 18]. Five studies applied cohort design with two utilizing a prospective approach [3, 8, 15, 20, 22]. One study was a case-control design [23] and three studies were randomized control trials (RCT) [1, 10, 16]. The RCT by Katz et al. (2020) summarized the results from two sequential trials. Trial 1 compared vented and

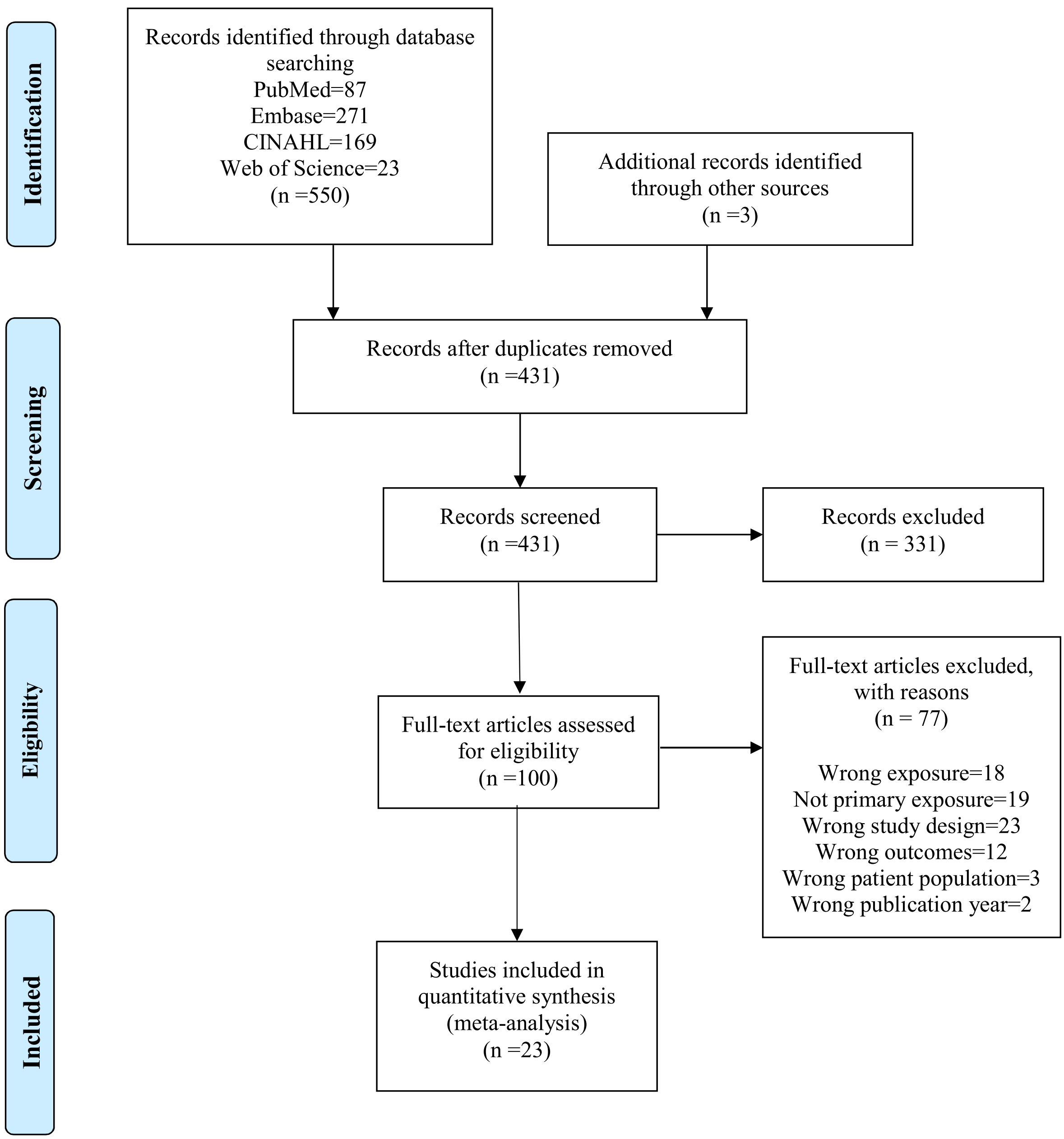

Fig. 1. PRISMA Flow Diagram of Study Selection Process.

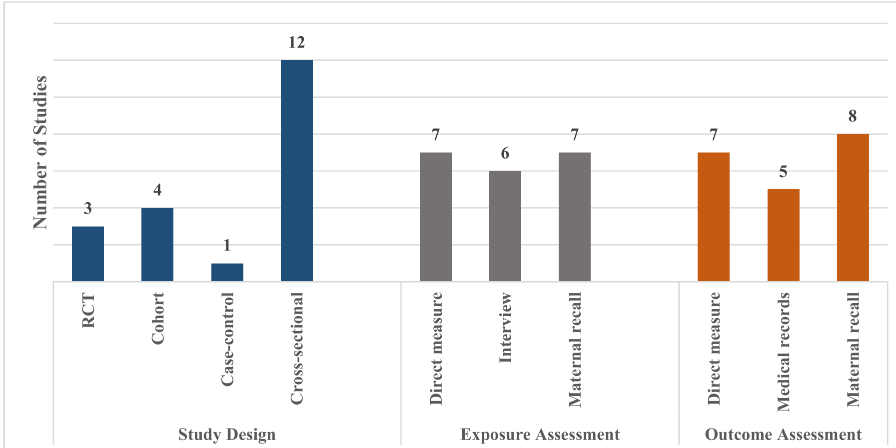

Fig. 2. Study design, exposure and outcome assessment measures for outcomes of birthweight, low birthweight and small for gestational age.

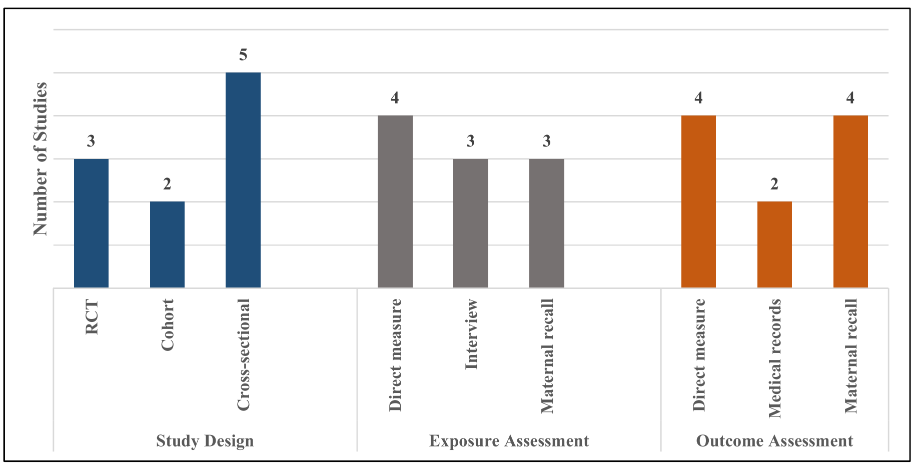

Fig. 3. Study design, exposure and outcome assessment measures for outcomes of stillbirth, preterm birth and spontaneous abortion.

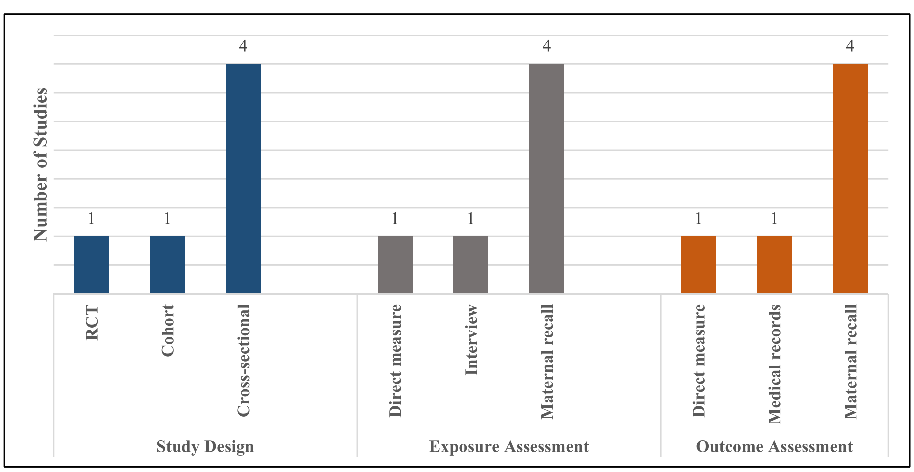

Fig. 4. Study design, exposure and outcome assessment measures for neonatal mortality.

traditional stoves while Trial 2 compared vented biomass with LPG stoves. This review only included data from Trial 2. Quinn et al. (2021) presented the exposure-response data of both arms of the Ghana Randomized Air Pollution and Health Study (GRAPHS) RCT stove intervention. The included studies were conducted in fifteen different countries: Bangladesh, China, Ghana, Guatemala, India, Indonesia, Kenya, Malawi, Nepal, Nigeria, Pakistan, Peru, Sri Lanka, Tanzania, and Zambia. See Supplement #2 for a map of global solid fuel use and countries included study settings.

The categorization of cooking fuel varied across studies. A total of six studies focused on HAP from one specific fuel on birth outcomes [1, 2, 10, 13, 19, 21]. Five studies investigated two or more of types of cooking fuels and their individual impact on outcomes [3, 7, 8, 9, 23], while seven studies categorized fuels into two groups of polluting/unclean or clean [6, 12, 14, 15, 17, 18, 20] and three as either solid fuels or non-solid [4, 5, 11]. The clean fuel comparison groups ranged from LPG, gas (biogas/natural gas) and electricity. Kerosene was categorized as a polluting fuel in ten studies [1–3, 6, 7, 9, 14, 15, 17, 20] and a non-polluting fuel in three studies [4, 11, 18]. Islam and Mohanty (2021b) analyzed a gradient of cooking fuels in order to quantify differences in mean birthweight by fuel type.

HAP exposure was either directly or indirectly assessed. Sixteen of the included studies indirectly assessed exposure to household air pollution during pregnancy through interviews or surveys asking about stove and/or fuel type [2, 4–9, 11, 12, 14, 15, 17–21]. Among studies that directly assessed HAP exposure, there were differences in collection timing, location and pollutants measured. Six studies directly measured HAP exposure with three using personal CO and/or PM monitors [1, 16, 22] worn during pregnancy, four measuring PM [3, 10, 13, 22] and three collecting CO kitchen concentrations [10, 22, 23]. The direct measures varied in length of sampling time of exposure collection ranging from 3 consecutive days [1, 3, 13, 22], 48 h [16, 23] to two measurements over 21.7 h [10]. Balakrishan et al. (2015) estimated exposure during each trimester by directly measuring an average of three 24-h kitchen $PM_{2.5}$ concentration levels as well as a 24-h kitchen measure of $PM_{2.5}$ in a subset of cohort participants. Mukherjee et al. (2015) recorded the mean direct kitchen PM_{10} exposure of randomly selected households over a three-day period. Wylie et al. (2017) measured personal and kitchen CO exposure levels over a 72-h period and personal $PM_{2.5}$ exposure during the first and third 24-h of the CO measurement. Yucra et al. (2014) measured kitchen CO concentrations over a 48-h period among a specified case and control sub-sample. Two RCT studies collected data on kitchen air pollutant concentrations of $PM_{2.5}$ and CO as well as intervention stove type as a measure of exposure [1, 10]. Alexander et al. (2018) also measured direct personal exposure to $PM_{2.5}$ and CO for three consecutive days during second trimester and third trimester. Quinn et al. (2021) calculated a composite measure of CO exposure using a series of 48-h-average personal CO monitoring sessions collected during four different points in pregnancy.

In terms of outcomes, birthweight and low birth weight were the most frequently reported health outcomes with twelve studies [1–3, 6–10, 12, 16, 21, 22] and thirteen studies [3, 5, 6, 8, 10, 11, 13, 16–21] respectively. Stillbirth [1, 11, 13–15, 17, 21], and small for gestational age [8, 10, 16, 19–21, 23] were reported in seven studies each. Preterm birth [1, 10, 16, 17, 20, 21] and neonatal mortality [1, 4, 11, 14, 15, 18] were reported in six studies. Spontaneous abortion was examined as an outcome in three studies [1, 13, 20]. Seven of the twenty-three included studies directly measured birth outcomes [1, 2, 9, 10, 16, 21, 22], seven relied on maternal recall [4, 5, 11, 13, 14, 17, 18], four collected data from medical records [3, 8, 19, 23] while the other five used a combination of interview and medical records [6, 7, 12, 15, 20].

3.3. Risk of bias within studies

Within the studies, confounding bias (e.g. unmeasured confounding) and detection bias (e.g. measurement error) in exposure characterization and outcome assessment led to high risk of bias scores. Across the domain of accounting for confounding bias, twelve out of twenty studies (60%) scored 'probably high risk of bias' [2, 5, 11–15, 17–20, 23]. The majority of studies in this rating category failed to account for important confounding and modifying variables cited in previous literature in either study design or analysis. Risk of bias in exposure characterization revealed seventeen out of twenty-three studies (74%) were either 'probably high risk' or 'definitely high risk' of bias [1, 2, 4–6, 8–15, 17–20]. Both exposure misclassification related to primary cooking fuel type serving as a proxy for household air pollution and potential recall bias due to self-reported cooking fuel use during pregnancy resulted in high risk of bias scores. Finally, confidence in the outcome was affected by outcome misclassification and measurement error. Evaluation of outcome assessment risk of bias determined seventeen of the twenty-three studies (74%) as either 'probably high risk' or 'definitely high risk' of bias [1–8, 9–14, 16–18, 23]. Common reasons for higher bias scores include failing to mention questionnaire or instrument validation, objectivity of the outcome assessment and blinding of those who assessed the outcomes. Conversely, a high proportion of the studies scored low risk of bias in the domains of selection and selective reporting bias. Selective bias refers to systematic differences between baseline characteristics of the groups and selective reporting bias is the selective inclusion of outcomes in the publication of the study on the basis of the results (Hutton and Williamson, 2000; Higgins and Green, 2011). The results of the risk of bias assessment are presented in Table 4.

3.4. Birthweight, low birth weight and small for gestational age outcomes

The association of cooking fuel type and birthweight (BW) was reported as adjusted mean difference by twelve studies [1–3, 6–10, 12, 16, 21, 22]. Eight of the twelve studies found statistically significant differences in birthweight based on cooking fuel types. Alexander et al. (2018) conducted a randomized ethanol stove intervention with kerosene/firewood (control) and reported the largest mean birthweight difference of 128 g (95% CI: 20, 236) after adjusting for marital status and BMI [1]. Birthweights were measured by maternal recall [6, 7, 12], hospital records [3, 6–8, 12] and use of a digital scale [1, 2, 9, 10, 16, 21, 22].

Thirteen studies that examined the association of household air pollution exposure from cooking fuel and low birth weight (LBW) (<2500 g) reported an increased adjusted odds ratio [3, 5, 6, 8, 11, 13, 16, 18–21], adjusted relative risk [10] or parameter posterior mean [17]. Statistically significant estimates of increased adjusted risk for LBW were reported in two studies comparing PM exposure measures [3, 13] and four studies among women using polluting fuel compared to cleaner cooking fuel [5, 8, 18, 19]. Balakrishnan et al. (2015) relied on direct PM exposure measurement methods to detect a significant increase in the odds of LBW with a $10 \mu g/m3$ increase in $PM_{2.5}$ (aOR: 1.02, 95% CI: 1.01, 1.04) [3]. Other significant associations of polluting fuel on LBW included coal fuel (aOR: 2.6, 95% CI: 1.1, 6.2) compared with non-solid fuels [5], wood fuel compared with non-solid fuels (aOR: 1.1, 95% CI: 1.0, 1.2) [5], and biomass fuel compared with gas fuels (aOR: 2.51, 95% CI: 1.26, 5.01) (aOR: 2.74, 95% CI: 1.08, 6.96) [8, 19]. Vakalopoulos et al. (2021) also assessed HAP exposure by stove type and HAP levels according to primary and secondary fuel type and ventilation. With this approach the authors reported significant increased risk of LBW with traditional biomass stoves versus clean stoves (aOR: 3.23, 95% CI: 1.17, 8.89).

Outcome assessment for LBW varied across studies. LBW outcomes were obtained from maternal recall of child size at birth [5, 6, 11, 13, 17, 18, 20], hospital records [3, 6, 8, 19, 20] and use of a digital scale [10,16, 21]. For both birthweight and LBW, two studies varied on inclusion of babies weighed at birth [1, 2], 24 h after birth [21, 22], 48 h [9] and within 72 h after birth [10, 16]. Digital scale brand and/or precision of measurement up to 10-g readability is addressed in three studies [10, 16, 20] while one reports the non-specific scales used on labor units [22] while the last mentions a pediatric weighing machine [9].

The selected seven studies that measured the effect of HAP from cooking fuel on SGA reported outcomes as adjusted odds ratios [8, 16, 19, 20, 21, 23] or adjusted relative risk [10]. Two studies found a statistically significant increased risk of SGA (aOR: 1.87, 95% CI: 1.03, 3.41) and (aOR: 4.53, 95% CI: 1.33, 15.49), respectively among women using biomass versus those who used clean fuel/gas during pregnancy [19, 23]. Compared to cleaner fuel stoves (mainly LPG), traditional biomass stoves also demonstrated a significant association with SGA (aOR: 2.64, 95% CI: 1.27, 4.91) [19]. In determining the outcome of small for gestational age (SGA), one study calculated gestational age using self-reported last menstrual period (LMP) confirmed by ultrasound and digital scale birthweight measurements [8], one only used self-reported LMP and digital scale at birth [10], another relied on birth card records [19] and one study combined digital scale measurements with New Ballard estimations for gestational age [21]. One study categorized SGA with birthweight from hospital records and gestational age from LMP as well as newborn maturity using the Capurro method [23]. The RCT by Quinn et al. (2021) calculated gestational age by ultrasound and birthweight with digital scale within 72 hrs of birth [16]. Utilizing WHO methodology, Quinn et al. (2021) also created a country specific curve for birthweight percentiles to accurately capture SGA infants.

3.5. *Spontaneous abortion, preterm birth, stillbirth outcomes*

The impact of cooking fuel on spontaneous abortion (SAB) was reported in three studies who defined SAB as fetal death <20 weeks gestation and reported as an adjusted odds ratio in two studies [13, 20] and <24 weeks gestation reported as an adjusted risk ratio in the third study [1]. While not significant, Weber et al. (2020) found a positive association between unclean fuel use and spontaneous abortion (OR: 2.10, 95% CI: 0.91, 4.81). The authors noted the rate of SAB may be underestimated because women with early miscarriages may not have joined the cohort prior to a SAB event. Mukherjee et al. (2015) found an increased risk of SAB with higher levels of PM_{10} from biomass fuel use (aOR: 3.12, 95% CI: 1.07, 4.17) compared to LPG fuel. SAB outcome assessment was obtained through participant recall [13, 20] and medical records [1, 20].

The outcome of preterm birth (PTB) (birth occurring before 37 weeks gestation) was ascertained by six studies and reported in adjusted risk ratios [1, 10], adjusted odds ratios [16, 20, 21] and parameter posterior mean [17]. In a cross-sectional study by Wylie et al. (2014), cooking with wood fuel was significantly associated with an increased risk of PTB (aOR: 2.29, 95% CI: 1.24, 4.21) compared to PTB in the gas fuel group. The authors only looked at a dichotomous measurement of primary cooking fuel and did not capture variability in possible use of multiple fuels, or stove stacking. PTB outcomes were collected from maternal recall [17], hospital records [20], new Ballard estimation [21] and field workers at delivery for the RCT studies [1,10, 16].

Seven studies examined the outcome of stillbirth reported in adjusted odds ratios [11, 13–15, 17, 21] and relative risk [1]. The dating of stillbirth varied from fetal death after 24 weeks [1], 28 weeks [11, 13], to any pregnancy that did not result in the birth of a live child including miscarriage [17]. Patel et al. (2015) differentiated stillbirths by macerated (death before onset of labor) and non-macerated (presumed intrapartum death). Both categories of stillbirth demonstrated significantly higher odds of stillbirth comparing with polluting fuels verses cleaner fuels. Stillbirth outcome assessment was obtained through maternal recall [11, 13, 14, 17] and medical records [1, 15, 21].

3.6. *Neonatal mortality outcomes*

The association between unclean cooking fuel and neonatal mortality was reported as increased odds ratio in four studies [11, 14, 15, 18], increased hazard ratio in one study [4] and a risk ratio in a RCT study [1]. Neonatal mortality outcomes were defined as death between birth and 28 days of age by four studies [1, 4, 11, 18], separated into early neonatal mortality (0–6 days) by one study [14] and categorized as very early (0–2 days) and later neonatal mortality (3–28 days) by another study [15]. Cooking with polluting fuels was significantly associated with an increased risk of very early neonatal mortality (aOR:1.82, 95% CI: 1.47, 2.22), early neonatal mortality (aOR 1.46, 95% CI: 1.01, 2.10), and neonatal mortality (aOR:1.38, 95% CI: 1.14, 1.67) compared to households cooking with clean fuels [14, 15, 18]. Five studies relied on maternal recall for reporting neonatal mortality outcomes [4, 11, 14, 15, 18] while one study used hospital records [1].

4. Discussion

We found an association between adverse birth outcomes and HAP from cooking fuels in low- and middle-income countries in our systematic review. The reviewed studies presented evidence for an increased risk of low birth weight (LBW), preterm birth (PTB), small for gestational age (SGA), stillbirth, neonatal mortality and reduction in birthweight with solid fuel and kerosene use compared to cleaner fuels like gas and LPG. This review builds upon the systematic review by Amegah et al. (2014) noting the methodologic drawbacks around the lack of personal exposure monitoring methods and potential for outcome measurement bias. The field of exposure science has progressed to include more studies on a variety of birth outcomes beyond birthweight including three recently published randomized clean stove/fuel intervention trials. This change was evidenced by the increase in available studies meeting selection criteria with outcomes including SAB, SGA, PTB, stillbirth and neonatal mortality. Systematically reviewing the evidence illuminated several gaps in the current literature related to exposure assessment, outcome measurement and adjustment for confounders.

First, variability in the exposure assessment and lack of direct or personal exposure assessment during pregnancy and the neonatal period contributed to difficulty in interpreting results and comparing statistics across studies. The measurements of direct personal or kitchen exposure varied in PM size fraction, inclusion of CO exposure measures, sampling time and approach to capturing exposure during pregnancy. Failing to assess exposures over different times scales using integrated exposure measurements may underestimate true exposure (Clark et al., 2013; Ezzati et al., 2000). These longer, more time-integrated approaches capture variability of cooking and non-cooking exposures in the household (Clark et al., 2013). Wylie et al. (2017) observed a seasonal pattern of personal exposure to CO related to a hypothesized increase use of kerosene during the rainy season. Alexander et al. (2018) also noted personal $PM_{2.5}$ exposure levels were lower during the rainy season vs the dry season which complicated the effect of the intervention on exposure levels. Assessing HAP exposure during the first trimester, which may be critical periods for outcomes like spontaneous abortion, can deepen our understanding of mechanisms of PM exposure on fetal development. Quinn et al. (2021) began enrollment around 10+ weeks of gestation and monitored personal CO exposure over four 72-h sessions. Additionally, Balakrishnan et al. (2018) utilized serial measurements of 24-h household $PM_{2.5}$ concentrations across all three trimesters as the primary measure of exposure. Inaccurate quantification of exposure that does not objectively measure exposure data across all trimesters can lead to underestimation of the relationship between HAP and adverse birth outcomes (Pope et al., 2010). These observations highlight the need for original data collection incorporating personal exposure monitoring, cooking behaviors and ideally biomarkers of exposure (Amegah et al., 2014; Clark et al., 2013).

Household emissions from other pollutants such as trash burning, tobacco smoke, ambient air pollution and fuels for lighting and heating all contribute to HAP, making it more difficult to distill the effects of exposure from cooking fuels. The exposure classification also fluctuated between studies that aggregated fuel types into clean or polluting while others compared specific fuels or stove types and their impact on birth outcomes. While using reported primary fuel or stove type as the assessment of exposure is inexpensive, the approach can lead to exposure misclassification, if households use multiple stoves and fuel types, and cannot produce an accurate exposure-response association (Clark et al., 2013). Exposure misclassification can occur when studies focusing on primary fuel use overlook the practice of stove stacking, the use of a combination fuels or using traditional stoves next to clean stoves, and therefore misrepresent the impact of clean fuel cooking practices on personal exposure (Ruiz-Mercado and Masera, 2015; Shankar et al., 2020). Rather than focusing on adoption of primary use of clean fuels, studies should also focus on the discontinuation of traditional stoves and incorporation of monitoring of stove usage to understand changes in behavior. The higher risk of bias scores resulting from exposure misclassification due to self-report or inadequate measurement underscore how errors in exposure characterization can attenuate, strengthen or even invert the true relationship (OHAT, 2015; White, 2003).

Kerosene in particular poses a unique issue in fuel type classification with several studies placing kerosene as a polluting fuel and others as clean fuel. Amegah et al. (2014) noted a similar categorization discrepancy of kerosene in their review. Kerosene is a liquid fuel distilled from petroleum oil and is often advocated as a cleaner alternative to solid fuel in settings where LPG, gas and electricity are too expensive or not available (Lam et al., 2012). In 2021, WHO established new air quality guidelines (AQG) adjusting almost all acceptable AQG levels downwards and a review by Lam et al. (2012), concluded kerosene-fueled stoves elevate indoor PM concentrations well above the previous 2005 WHO guidelines (WHO, 2006; WHO, 2021). Kerosene fuel not only emits high quantities of PM, but the ultrafine particle size is much small than the diameter of solid fuel PM ensuring deep lung and vascular deposition (Lam et al., 2012). These discrepancies in exposure classification may affect the validity of the results.

Nine of the included studies utilized population-level DHS data [4–7, 11, 12, 14, 17, 18] and sixteen conducted interviews to assess HAP exposure [2, 4–9, 11, 12, 14, 15, 17–20]. Collecting data via survey relies on self-report often from births within 5 years of the survey leading to reporting and recall biases (Odo et al., 2021). DHS collects information on cooking fuel as a proxy to estimate HAP but does not include questions on non-cooking sources of pollution like lighting and heating contributing to exposure misclassification. Recently, the WHO created a harmonized survey questions for monitoring household energy use and SDG indicators to be incorporated in future DHS-style surveys as a means to monitor SDG indicators (WHO, 2019).

Second, assessing birth outcomes also exhibited variability across studies. The potential for maternal recall bias was reflected in the high risk of bias scores in outcome assessment. Ideally newborns birthweight is measured within the first hours of delivery before postnatal weight loss occurs (Marete et al., 2020). Because infants are expected to lose 5–10% of their weight in the first week of life, timely measurement using a well-calibrated scale measuring within 10 g increments for categorizing low birth weight and SGA is particularly important (Gladstone et al., 2021; Macdonald et al., 2003; Thompson et al., 2011). Training of field workers in reliable anthropometry methods is also essential for obtaining accurate categorizations of LBW and SGA babies. Imprecision in calculation of birthweight by rounding ($>$10 g), scale calibration or maternal recall can lead to digit bias and potential misclassification of birth outcomes like LBW (WHO, 2005).

In high poverty areas where unclean fuel use is prevalent, and where infants are born at home, or in hospitals using imprecise scales, accurate measurement of birthweight is intermittent and may influence birth outcome associations with HAP in studies analyzing secondary data (Pope et al., 2010). Stillbirth outcomes varied in definition as fetal death $\geq$20 weeks gestation by one study [15], $\geq$24 weeks in one study [1], $\geq$28 weeks in three studies [11, 13, 14], infant delivered without any sign of life [21] and any pregnancy that did not result in the birth of a live child including miscarriages [17]. Also, cases of stillbirth and neonatal mortality that occur in the home may not be recorded in hospital records or demographic survey data mitigating the true effect of HAP on serious adverse birth outcomes. Additionally, analyses of live births as the study population for adverse birth outcomes may be impacted by live-birth bias. Recognizing that an estimated 30–40% of fertilized eggs will not result in viable gestation, selective analysis of live births could lead to bias in the observed association vs an actual causal relationship (Neophytou et al., 2021; Raz et al., 2018).

Finally, the range of study designs added to the complexity of interpreting significant associations between HAP and birth outcomes. Most of the included studies are observational using cross-sectional, cohort or case-control designs with six analyzing large national DHS data. Only three studies were RCTs and did not utilize the measure of blinding of exposure or outcome in their study designs. The selected RCTs exhibited strengths and limitations. Alexander et al. (2018) demonstrated accurate health outcome assessments, conducted personal exposure and stove use monitoring while controlling for season in the exposure-response relationship. However, the small sample size ($n = 324$) may have lacked adequate power to detect smaller effects on outcomes. The authors mention the lack of reliable exposure assessments across both the second and third trimester as well as no measurements conducted during the first trimester. Katz et al. (2020) did not conduct personal exposure monitoring and by not measuring infant weight at birth within 24 h lacked adequate outcome assessment. The high ambient air pollution levels may also have modified the association between HAP and birth outcomes in both studies. Quinn et al. (2021) conducted repeated CO measures among a large sample size ($n = 1288$) using gold standard personal exposure monitoring methods in an attempt to distill the exposure-response relationship of the GRAPHS Trial cookstove intervention. Birth outcomes were directly measured by field workers within 72 h of birth using standardized anthropometric methods. The authors originally intended to include a single 72 h $PM_{2.5}$ exposure assessment but the data did not pass assurance/quality control checks. A recently launched RCT, Household Air Pollution Intervention Network (HAPIN) trial, is a multi-country trial to assess the effect of a randomized LPG stove intervention on maternal, child, and adult health outcomes (Clasen et al., 2020). The investigators plan on using repeated 24-h personal and indirect measure of PM and CO as well as black carbon to capture exposure-response associations.

None of the studies included in this review cited a theoretical framework explaining the mechanisms relating HAP to adverse birth outcomes. Capturing the multidimensional nature of socioeconomic status (SES) requires thoughtful justification for included socioeconomic factors and adequate adjustment for poverty as an explanatory pathway influencing health outcomes (Braveman et al., 2005). Except for RCT designed studies where randomization can remove confounding factors in groups, controlling for poverty and SES varied widely across studies.

The main strength of this systematic review was the organization of a breadth of outcome variables into adverse birth outcomes. This format clearly identified significant main findings. The search was conducted in two languages across four databases and built upon references from the two previous reviews (Amegah et al., 2014; Pope et al., 2010). Limitations of the review include a lack of grey literature. The search resulted in studies conducted in only 15 countries and the reviewers may have missed key outcomes specific to other countries. Also, the chosen outcome measures and type of cooking fuels for each study were highly variable making it difficult to compare statistics across studies.

5. Conclusion

This review demonstrates the current evidence on the relationship of HAP from cooking fuel on adverse and serious adverse birth outcomes. The lack of consistent methodological quality limited the validity of the evidence, and more research is needed to establish a causal relationship between HAP and birth outcomes. A deeper understanding of the pathways of HAP exposure via maternal factors remains an area of future research. The UN Sustainable Development Goals support evidence-based policy and their progress over the next ten years may influence political will in low- and middle-income countries to improve access to clean household energy solutions (Amegah et al., 2014). Considering the Sustainable Development Goals, the findings from this review will continue to guide researchers and policy makers to identify opportunities to address household air pollution for vulnerable populations internationally.

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Study registration

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Author statement

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Declaration of competing interest

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Appendix A. Supplementary data

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References

Alexander, D.A., Northcross, A., Karrison, T., Morhasson-Bello, O., Wilson, N., Atalabi, O. M., Dutta, A., Adu, D., Ibigbami, T., Olamijulo, J., Adepoju, D., Ojengbede, O., Olopade, C.O., 2018. Pregnancy outcomes and ethanol cook stove intervention: a randomized-controlled trial in Ibadan, Nigeria. Environ. Int. 111, 152–163. https://doi.org/10.1016/j.envint.2017.11.021.

Amegah, A.K., Jaakkola, J.J., 2016. Household air pollution and the sustainable development goals. Bull. World Health Organ. 94 (3), 215–221. https://doi.org/10.2471/BLT.15.155812.

Amegah, A.K., Quansah, R., Jaakkola, J.J., 2014. Household air pollution from solid fuel use and risk of adverse pregnancy outcomes: a systematic review and meta-analysis of the empirical evidence. PLoS One 9 (12), e113920. https://doi.org/10.1371/journal.pone.0113920.

Balakrishnan, K., Ghosh, S., Thangavel, G., Sambandam, S., Mukhopadhyay, K., Puttaswamy, N., Sadasivam, A., Ramaswamy, P., Johnson, P., Kuppuswamy, R., Natesan, D., Maheshwari, U., Natarajan, A., Rajendran, G., Ramasami, R., Madhav, S., Manivannan, S., Nargunanadan, S., Natarajan, S., Thanasekaraan, V., 2018. Exposures to fine particulate matter (PM2.5) and birthweight in a rural-urban, mother-child cohort in Tamil Nadu, India. Environ. Res. 161, 524–531. https://doi.org/10.1016/j.envres.2017.11.050.

Blencowe, H., Cousens, S., Oestergaard, M.Z., Chou, D., Moller, A.-B., Narwal, R., Adler, A., Vera Garcia, C., Rohde, S., Say, L., Lawn, J.E., 2012. National, regional, and worldwide estimates of preterm birth rates in the year 2010 with time trends since 1990 for selected countries: a systematic analysis and implications. Lancet 379 (9832), 2162–2172. https://doi.org/10.1016/s0140-6736(12)60820-4.

Braveman, P.A., Cubbin, C., Egerter, S., Chideya, S., Marchi, K.S., Metzler, M., Posner, S., 2005. Socioeconomic status in health ResearchOne size does not fit all. J. Am. Med. Assoc. 294 (22), 2879–2888. https://doi.org/10.1001/jama.294.22.2879.

Burnett, R.T., Pope 3rd, C.A., Ezzati, M., Olives, C., Lim, S.S., Mehta, S., Shin, H.H., Singh, G., Hubbell, B., Brauer, M., Anderson, H.R., Smith, K.R., Balmes, J.R., Bruce, N.G., Kan, H., Laden, F., Prüss-Ustün, A., Turner, M.C., Gapstur, S.M., Diver, W.R., Cohen, A., 2014. An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. Environ. Health Perspect. 122 (4), 397–403. https://doi.org/10.1289/ehp.1307049.

Clark, M.L., Peel, J.L., Balakrishnan, K., Breysse, P.N., Chillrud, S.N., Naeher, L.P., Rodes, C.E., Vette, A.F., Balbus, J.M., 2013. Health and household air pollution from solid fuel use: the need for improved exposure assessment. Environ. Health Perspect. 121 (10), 1120–1128. https://doi.org/10.1289/ehp.1206429.

Clasen, T., Checkley, W., Peel, J.L., Balakrishnan, K., McCracken, J.P., Rosa, G., Thompson, L.M., Barr, D.B., Clark, M.L., Johnson, M.A., Waller, L.A., Jaacks, L.M., Steenland, K., Miranda, J.J., Chang, H.H., Kim, D.Y., McCollum, E.D., Davila-Roman, V.G., Papageorghiou, A., Rosenthal, J.P., Investigators, H.A.P.I.N., 2020. Design and rationale of the HAPIN Study: a multicountry randomized controlled trial to assess the effect of liquefied petroleum gas stove and continuous fuel distribution. Environ. Health Perspect. 128 (4), 47008. https://doi-org.ucsf.idm.oclc.org/10.1289/EHP6407.

Covidence systematic review software, Veritas Health Innovation, Melbourne, Australia. www.covidence.org.

Dherani, M., Pope, D., Mascarenhas, M., Smith, K.R., Weber, M., Bruce, N., 2008. Indoor air pollution from unprocessed solid fuel use and pneumonia risk in children aged under five years: a systematic review and meta-analysis. Bull. World Health Organ. 86 (5), 390–398C. https://doi.org/10.2471/blt.07.044529.

Ezzati, M., Saleh, H., Kammen, D.M., 2000. The contributions of emissions and spatial microenvironments to exposure to indoor air pollution from biomass combustion in Kenya. Environ. Health Perspect. 108 (9), 833–839. https://doi.org/10.2307/3434990.

Ghosh, R., Cuasey, K., Burkart, K., Wozniak, S., Cohen, A., Brauer, M., 2021. Ambient and household $PM_{2.5}$ pollution and adverse perinatal outcomes: a meta-regression and analysis of attributable global burden for 204 countries and territories. PLoS Med. 18 (9), e1003718 https://doi.org/10.1371/journal.pmed.1003718.

Gibson, A., Noguchi, L., Kinney, M.V., Blencowe, H., Freedman, L., Mofokeng, T., Chopra, M., Dube, Q., Ntirushwa, D., Nguku, A., Banerjee, A., Rajbhandari, S., Galadanci, H., Baye, M.L., Zyaee, P., Tadesse, L., Eltayeb, D., Gogoi, A., El Arifeen, S., Sow, S., Kuma-Aboagye, P., 2021. Galvanizing collective action to accelerate reductions in maternal and newborn mortality and prevention of stillbirths. Glob Health Sci Pract. https://doi.org/10.9745/ghsp-d-20-00575.

Gladstone, M.E., Salim, N., Ogillo, K., Shamba, D., Gore-Langton, G., Day, L.T., Blencowe, H., Lawn, J.E., 2021. Birthweight measurement processes and perceived value: qualitative research in one EN-BIRTH study hospital in Tanzania. BMC Pregnancy Childbirth *21* (232). https://doi.org/10.1186/s12884-020-03356-2.

Higgins, J., Green, S., 2011. Cochrane Handbook for Systematic Reviews of Interventions. *The Cochrane Collaboration*. https://handbook-5-1.cochrane.org/.

Hutton, J.L., Williamson, P.R., 2000. Bias in meta-analysis due to outcome variable selection within studies. J. Roy. Stat. Soc. C Appl. Stat. 49, 359–370. https://doi.org/10.1111/1467-9876.00197.

Institute for Health Metrics and Evaluation (IHME), 2018. State of the Global Air: A Special Report on Global Exposure to Air Pollution and its Disease Burden 2018. https://www.stateofglobalair.org/sites/default/files/soga-2018-report.pdf.

Islam, S., Mohanty, S.K., 2021b. Understanding the association between gradient of cooking fuels and low birth weight in India. SSM-Population Health 12, 100732. https://doi.org/10.1016/j.ssmph.2021.100732.

Katz, J., Tielsch, J.M., Khatry, S.K., Shrestha, L., Breysse, P., Zeger, S.L., Kozuki, N., Checkley, W., LeClerq, S.C., Mullany, L.C., 2020. Impact of Improved Biomass and Liquid Petroleum Gas Stoves on Birth Outcomes in Rural Nepal: Results of 2 Randomized Trials. Global Health Science and Practice 8 (3), 372–382. https://doi.org/10.9745/GHSP-D-20-00011.

Kurmi, O.P., Semple, S., Simkhada, P., Smith, W.C., Ayres, J.G., 2010. COPD and chronic bronchitis risk of indoor air pollution from solid fuel: a systematic review and meta-analysis. Thorax 65 (3), 221–228. https://doi.org/10.1136/thx.2009.124644.

Kurmi, O.P., Arya, P.H., Lam, K.B., Sorahan, T., Ayres, J.G., 2012a. Lung cancer risk and solid fuel smoke exposure: a systematic review and meta-analysis. E*ur. Respir. J.* 40 (5), 1228–1237. https://doi.org/10.1183/09031936.00099511.

Kurmi, O.P., Lam, K.B., Ayres, J.G., 2012b. Indoor air pollution and the lung in low- and medium-income countries. Eur. Respir. J. 40 (1), 239–254. https://doi.org/10.1183/09031936.00190211.

Lam, N.L., Smith, K.R., Gauthier, A., Bates, M.N., 2012. Kerosene: a review of household uses and their hazards in low- and middle-income countries. J. Toxicol. Environ. Health B Crit. Rev. 15 (6), 396–432. https://doi.org/10.1080/10937404.2012.710134.

Lee, K.K., Bing, R., Kiang, J., Bashir, S., Spath, N., Stelzle, D., Mortimer, K., Bularga, A., Doudesis, D., Joshi, S.S., Strachan, F., Gumy, S., Adair-Rohani, H., Attia, E.F., Chung, M.H., Miller, M.R., Newby, D.E., Mills, N.L., McAllister, D.A., Shah, A., 2020. Adverse health effects associated with household air pollution: a systematic review , meta-analysis, and burden estimation study. The Lancet. Global health 8 (11), e1427–e1434. https://doi-org.ucsf.idm.oclc.org/10.1016/S2214-109X(20)30343-0.

Li, N., Sioutas, C., Cho, A., Schmitz, D., Misra, C., Sempf, J., Wang, M., Oberley, T., Froines, J., Nel, A., 2003. Ultrafine particulate pollutants induce oxidative stress and mitochondrial damage. Environ. Health Perspect. 111 (4), 455–460. https://doi.org/10.1289/ehp.6000.

Macdonald, P.D., Ross, S.R., Grant, L., Young, D., 2003. Neonatal weight loss in breast and formula fed infants. Arch. Dis. Child. Fetal Neonatal Ed. 88 (6), F472–F476. https://doi.org/10.1136/fn.88.6.F472.

Marete, I., Ekhaguere, O., Bann, C.M., Bucher, S.L., Nyongesa, P., Patel, A.B., Hibberd, P. L., Saleem, S., Goldenberg, R.L., Goudar, S.S., Derman, R.J., Garces, A.L., Krebs, N.F., Chomba, E., Carlo, W.A., Lokangaka, A., Bauserman, M., Koso-Thomas, M., Moore, J. L., McClure, E.M., Esamai, F., 2020. Regional trends in birth weight in low- and middle-income countries 2013-2018. Reprod. Health 17 (Suppl. 3), 176. https://doi.org/10.1186/s12978-020-01026-2.

McDonald, C.R., Weckman, A.M., Wright, J.K., Conroy, A.L., Kain, K.C., 2020. Pregnant women in low- and middle-income countries require a special focus during the COVID-19 pandemic [opinion]. Front. Glob. Women's Health 1 (6). https://doi.org/10.3389/fgwh.2020.564560.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., The, P.G., 2009. Preferred reporting Items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 6 (7), e1000097 https://doi.org/10.1371/journal.pmed.1000097.

Morgan, R.L., Whaley, P., Thayer, K.A., Schünemann, H.J., 2018. Identifying the PECO: A framework for formulating good questions to explore the association of environmental and other exposures with health outcomes. Environ. Int. 121 (Pt 1), 1027–1031. https://doi.org/10.1016/j.envint.2018.07.015.

Mukherjee, S., Siddique, S., Chakraborty, S., Bhattacharya, P., Banerjee, M., Roychoudhury, S., Lahiri, T., Ray, M.R., 2015. Adverse reproductive health outcomes in pre-menopausal Indian women chronically exposed to biomass smoke. J. Publ. Health 23 (6), 363–372. https://doi.org/10.1007/s10389-015-0690-7.

Neophytou, A.M., Kioumourtzoglou, M.A., Goin, D.E., Darwin, K.C., Casey, J.A., 2021. Educational note: addressing special cases of bias that frequently occur in perinatal epidemiology. Int. J. Epidemiol. 50 (1), 337–345. https://doi-org.ucsf.idm.oclc.org/10.1093/ije/dyaa252.

Odo, D.B., Yang, I.A., Knibbs, L.D., 2021. A systematic review and appraisal of epidemiological studies on household fuel use and its health effects using demographic and health surveys. Int. J. Environ. Res. Publ. Health 18 (4). https://doi.org/10.3390/ijerph18041411.

Office of Health Assessment and Translation (OHAT), 2015. OHAT Risk Of Bias Rating Tool For Human And Animal Studies. https://ntp.niehs.nih.gov/ntp/ohat/pubs/riskofbiastool_508.pdf.

Patel, A.B., Meleth, S., Pasha, O., Goudar, S.S., Esamai, F., Garces, A.L., Chomba, E., McClure, E.M., Wright, L.L., Koso-Thomas, M., Moore, J.L., Saleem, S., Liechty, E.A., Goldenberg, R.L., Derman, R.J., Hambidge, K.M., Carlo, W.A., Hibberd, P.L., 2015. Impact of exposure to cooking fuels on stillbirths, perinatal, very early and late neonatal mortality - a multicenter prospective cohort study in rural communities in India, Pakistan, Kenya, Zambia and Guatemala. Maternal Health, Neonatol. Perinatol. 1 (1) https://doi.org/10.1186/s40748-015-0019-0, 18–18.

Pope, D.P., Mishra, V., Thompson, L., Siddiqui, A.R., Rehfuess, E.A., Weber, M., Bruce, N. G., 2010. Risk of low birth weight and stillbirth associated with indoor air pollution from solid fuel use in developing countries. Epidemiol. Rev. 32, 70–81. https://doi.org/10.1093/epirev/mxq005.

Quinn, A.K., Adjei, I.A., Ae-Ngibise, K.A., Agyei, O., Boamah-Kaali, E.A., Burkart, K., Carrión, D., Chillrud, S.N., Gould, C.F., Gyaase, S., Jack, D.W., Kaali, S., Kinney, P.L., Lee, A.G., Mujtaba, M.N., Oppong, F.B., Owusu-Agyei, S., Yawson, A., Wylie, B.J., Asante, K.P., 2021. Prenatal household air pollutant exposure is associated with reduced size and gestational age at birth among a cohort of Ghanaian infants. Environ. Int. 155, 106659. https://doi.org/10.1016/j.envint.2021.106659. Advance online publication.

Raz, R., Kioumourtzoglou, M., Weisskopf, M.G., 2018. Live-birth bias and observed associations between air pollution and autism. Am. J. Epidemiol. 187 (11), 2292–2296. https://doi-org.ucsf.idm.oclc.org/10.1093/aje/kwy172.

Ruiz-Mercado, I., Masera, O., 2015. Patterns of stove use in the context of fuel-device stacking: rationale and implications. EcoHealth 12 (1), 42–56. https://doi.org/10.1007/s10393-015-1009-4.

Sedgh, G., Singh, S., Hussain, R., 2014. Intended and unintended pregnancies worldwide in 2012 and recent trends. Stud. Fam. Plann. 45 (3), 301–314. https://doi.org/10.1111/j.1728-4465.2014.00393.x.

Shankar, A.V., Quinn, A., Dickinson, K.L., Williams, K.N., Masera, O., Charron, D., Jack, D., Hyman, J., Pillarisetti, A., Bailis, R., Kumar, P., Ruiz-Mercado, I., Rosenthal, J., 2020. Everybody Stacks: lessons from household energy case studies to inform design principles for clean energy transitions. Energy Pol. 141 https://doi.org/10.1016/j.enpol.2020.111468.

Smith, K.R., 1993. Fuel combustion, air pollution exposure, and health: the situation in developing countries. Annu. Rev. Energy Environ. 18 (1), 529–566. https://doi.org/10.1146/annurev.eg.18.110193.002525.

Smith, K.R., Mehta, S., Feuz, M., 2004. Indoor air pollution from household use of solid fuels. In: Exxati, M., Lopez, A.D., Rodgers, A., Murray, C.J.L. (Eds.), Comparative Quantification of Health Risk: Global and Regional Burden of Disease Due to Selected Major Risk Factors. WHO.

Smith, K.R., McCracken, J.P., Weber, M.W., Hubbard, A., Jenny, A., Thompson, L.M., Balmes, J., Diaz, A., Arana, B., Bruce, N., 2011. Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial. Lancet 378 (9804), 1717–1726. https://doi.org/10.1016/s0140-6736(11)60921-5.

Smith, K.R., Bruce, N., Balakrishnan, K., Adair-Rohani, H., Balmes, J., Chafe, Z., Dherani, M., Hosgood, H.D., Mehta, S., Pope, D., Rehfuess, E., 2014. Millions dead: how do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution. Annu. Rev. Publ. Health 35, 185–206. https://doi.org/10.1146/annurev-publhealth-032013-182356.

The Lancet, 2016. The Lancet Ending Preventable Stillbirths Series: an Executive Summary for the Lancet's Series. https://www.thelancet.com/pb/assets/raw/Lancet/stories/series.

Thompson, L.M., Bruce, N., Eskenazi, B., Diaz, A., Pope, D., Smith, K.R., 2011. Impact of reduced maternal exposures to wood smoke from an introduced chimney stove on newborn birth weight in rural Guatemala. Environ. Health Perspect. 119 (10), 1489–1494. https://doi.org/10.1289/ehp.1002928.

United Nations (UN), 2015. Transforming Our World: the 2030 Agenda for Sustainable Development. United Nations, New York. http://ec.europa.eu/environment/sustainabledevelopment/SDGs/index_en.htm.

United Nations Children's Fund (UNICEF), 2019. UNICEF-WHO Low Birthweight Estimates: Levels and Trends 2000–2015. https://apps.who.int/iris/bitstream/handle/10665/324783/WHO-NMH-NHD-19.21-eng.pdf?ua=1.

Vakalopoulos, A., Dharmage, S.C., Dharmaratne, S., Jayasinghe, P., Lall, O., Ambrose, I., Weerasooriya, R., Bui, D.S., Yasaratne, D., Heyworth, J., Bowatte, G., 2021. Household air pollution from biomass fuel for cooking and adverse fetal growth outcomes in rural Sri Lanka. Int. J. Environ. Res. Publ. Health 18. https://doi.org/10.3390/ijerph18041878, 1878.

Weber, E., Adu-Bonsaffoh, K., Vermeulen, R., Klipstein-Grobusch, K., Grobbee, D.E., Browne, J.L., Downward, G.S., 2020. Household fuel use and adverse pregnancy outcomes in a Ghanaian cohort study. Reprod. Health 17 (1). https://doi.org/10.1186/s12978-020-0878-3, 29–8.

White, E., 2003. Design and interpretation of studies of differential exposure measurement error. Am. J. Epidemiol. 157 (5), 380–387. https://doi.org/10.1093/aje/kwf203.

World Bank, 2021. The world by income and region. https://datatopics.worldbank.org/world-development-indicators/the-world-by-income-and-region.html.

World Health Organization (WHO), 2005. Monitoring low birth weight: an evaluation of international estimates and an updated estimation procedure. Bull. World Health Organ. 83, 178–185.

World Health Organization (WHO), 2006. WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide: Global Update 2005. https://apps.who.intirisbitstreamhandle10665/69477WHO_SDE_PHE_OEH_06.02_eng.pdf?sequence=1.

World Health Organization (WHO), 2007. Indoor Air Pollution: National Burden of Disease Estimates. https://www.who.int/airpollution/publications/nationalburden/en/.

World Health Organization (WHO), 2014. Global Nutrition Targets 2025: Low Birth Weight Policy Brief. https://www.who.int/nutrition/publications/globaltargets2025_policybrief_lbw/en/.

World Health Organization (WHO), 2018. Preterm Birth. https://www.who.int/news-room/fact-sheets/detail/preterm-birth.

World Health Organization (WHO), 2019. Harmonized Survey Questions for Monitoring Household Energy Use and SDG Indicators 7.1.1 and 7.1.2. https://www.who.int/airpollution/household/1_Harmonized_household_energy_survey_questions-list_format_final_Nov2019.pdf?ua=1.

World Health Organization (WHO), 2021. Proportion of the Population with Primary Reliance on Polluting Fuels and Technology for Cooking. The Global Health Observatory. https://www.who.int/data/gho/data/indicators/indicator-details/GHO/gho-phe-population-with-primary-reliance-on-polluting-fuels-and-technologies-for-cooking-proportion.

World Health Organization, 2021. WHO global air quality guidelines: particulate matter (‎PM2.5 and PM10)‎, ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://apps.who.int/iris/handle/10665/345329.

Wylie, B.J., Coull, B.A., Hamer, D.H., Singh, M.P., Jack, D., Yeboah-Antwi, K., Sabin, L., Singh, N., MacLeod, W.B., 2014. Impact of biomass fuels on pregnancy outcomes in central East India. Environmental Health 13 (1). https://doi.org/10.1186/1476-069X-13-1, 1–1.

Wylie, B.J., Kishashu, Y., Matechi, E., Zhou, Z., Coull, B., Abioye, A.I., Dionisio, K.L., Mugusi, F.M., Premji, Z., Fawzi, W.W., Hauser, R.B., Ezzati, M., 2017. Maternal exposure to carbon monoxide and fine particulate matter during pregnancy in an urban Tanzanian cohort. Indoor Air 27, 136–146.

Yucra, S., Tapia, V., Steenland, K., Naeher, L., Gonzales, G., 2014. Maternal exposure to biomass smoke and carbon monoxide in relation to adverse pregnancy outcome in two high altitude cities of Peru. Environmental Research 130, 29–33. https://doi.org/10.1016/j.envres.2014.01.008.

Further reading

Islam, S., Mohanty, S.K., 2021a. Maternal exposure to cooking smoke and risk of low birth weight in India. Sci. Total Environ. 774, 14717. https://doi.org/10.1016/j.scitotenv.2021.145717.