The Effects of Indoor Air Pollution from Solid Fuel Burning on Neurological and Neuropsychiatric Diseases - A Review of Epidemiological Evidence

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Abstract. Indoor air pollution (IAP) from using unclean fuel has brought huge disease and economic burden, and we aim to analyse the effect of IAP from using solid fuels on neurodevelopmental disorders (NDDs), cognitive impairment and neurodegenerative diseases (NDGDs), as well as mental disorders. We conducted a search of PubMed database from inception to 29th July 2025. We found that the number of studies focusing on the effects of solid fuel burning on NDDs and NDGDs is limited, and the association remains uncertain. However, the evidence regarding cognitive impairment and mental disorders was abundant, and most studies indicated that participants using solid cooking fuels had a higher risk of these diseases. The most important common limitation is that many studies formulaically analyse big health data sets, which leads to problems like residual confounding due to the incomplete information in the datasets. Policy makers of developing countries can prioritize gas as the transitional option from solid fuels to electricity, while developed countries should attach importance to policies related to wood heating. It is crucial to implement policy such as providing financial incentives and offering public education.

Keywords: Indoor air pollution, Solid fuel, Neurodevelopmental disorders, Cognitive impairment, Neurodegenerative diseases, Mental disorders

1 Introduction

It is estimated that there are 2.8 billion people worldwide using solid fuels and simple stoves, and the indoor air pollution (IAP) caused by them has brought a huge disease and economic burden. The use of solid fuels (e.g., wood, coal, crop waste and charcoal) in households causes the emission of several indoor air pollutants, such as particulate matter (PM), sulphur oxides, carbon monoxide (CO), heavy metals and volatile organic

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compounds (VOCs). These pollutants can adversely affect human health, causing diseases include stroke, ischemic heart disease, lower respiratory infections and chronic obstructive pulmonary disease (COPD). The global loss of healthy life years due to IAP was estimated to be 86 million in 2019 [1], and the global welfare losses from household air pollution was estimated to be 1.516 trillion dollars in 2013 [2].

Humans spend about 90% of their time indoors [1], and indoor air quality is a significant factor of indoor environment quality. In addition, neurodevelopmental disorders (NDDs), cognitive impairment (CI) and neurodegenerative diseases (NDGDs), as well as mental disorders have imposed huge health and economic burden. Thus, it is important to analyse the impact of IAP on these neurological and neuropsychiatric diseases. Here, CI and NDGDs were discussed together because NDGDs has a long preclinical period and CI is closely associated with NDGDs such as Alzheimer's disease (AD) and Parkinson disease (PD) [3, 4]. We found that the number of studies related to NDGDs was limited, while literature focusing on CI was abundant. Therefore, the impact of IAP on CI may also imply the impact on NDGDs. Previous research has reported that air pollution can exert neurotoxicity across life span. Mother exposed to air pollutants (e.g., particulate matter, sulfur and iron) can affect placenta and the development of fetal brain. After birth, air pollutants can enter the blood circulation after being inhaled and then travel into the brain. The shared mechanisms by which air pollutants affect NDDs and NDGDs may include inflammation and activation of microglia, altered glutamatergic function and mitochondrial dysfunction. These lead to shared outcomes of white matter damage and ventriculomegaly [5]. In addition, air pollutant can also affect mental health through neurostructural and neurofunctional changes (e.g., inflammation and oxidative stress, neurotransmitter change) in hippocampus or multiple brain regions [6]. Furthermore, epidemiological studies also explored the effect of IAP from solid fuel use on NDDs, CI and NDGDs, as well as mental disorders. Thus, we review the epidemiological evidence from PubMed, as well as provide suggestions for future research and policy formulation.

We performed search in PubMed from database inception to 29th July, 2025. The selection criteria are as follows. The exposure needs to be related to IAP due to solid fuel use, and the outcomes must be NDDs, NDGDs and mental disorders. The searching terms include "indoor air pollution", "autism spectrum disorder", "ADHD", "intellectual disability", "Alzheimer disease", "Parkinson disease", "cognitive dysfunction", "dementia", "depression" and "angst". We used the MeSH database to identify the terms and the synonym, and our search strategy incorporated MeSH terms and the possible expressions to ensure the comprehensive coverage of the literature. The search was limited to peer-reviewed epidemiological studies published in English. A total of 632 articles (81 on NDDs, 341 on CI and NDGDs, 210 on mental disorders) were found, of which 174 articles (23 on NDDs, 92 on CI and NDGDs, 59 on mental disorders) were selected for full-text reading. Finally, 57 studies (5 on NDDs, 31 on CI and NDGDs, 21 on mental disorders) met our selection criteria. However, we found that many articles focusing on cognitive impairment and mental disorders have similar research designs and conclusions, so we discussed the common findings of these studies and only selected some valuable articles for detailed discussion. The shared limitations were further summarized in section 5.

2 Neurodevelopmental Disorders

Neurodevelopmental disorders (NDDs) often manifest during developmental stages, typically manifest early in life (before entering elementary school) and are characterized by developmental deficiencies that impact the development of brain and nervous system, which in turn impacts individual, social, academic, or professional functioning. These diseases have brought huge health and economic burden. According to the survey, the incidence of ASD and ADHD in children ages 0-14 worldwide was 1,163,706.03 and 4,111,621.02 in 2021 respectively [7]. In 2019 alone, the total socioeconomic cost of ADHD in Australia came to about A$20.42 billion, of which A$10.19 billion was due to lost productivity. And the annual financial cost of ASD in the US is projected to reach $461 billion by 2025 [8, 9]. We selected three common NDDs: autism spectrum disorder (ASD), intellectual disability, attention deficit hyperactivity disorder (ADHD), but we did not find studies related to intellectual disability. Therefore, a total of 5 studies focusing on ADHD and ASD were discussed in this section.

The characteristics of the selected papers were shown in **Table 1**. In terms of ADHD, there is a study in Guangzhou which used a cross-sectional approach. It included 7,495 schoolchildren aged 6 to 12 and found a significant positive association between exposure to cooking oil smoke and a higher incidence of ADHD symptoms [10]. In addition to elementary school children, those affected by indoor air pollution may also include pregnant and preschool children. A prospective cohort study involving 42,983 mothers conducted between 2015 and 2017 concluded that maternal exposure to cooking fumes during pregnancy was significantly positively associated with the risk of hyperactive behaviour in their children at age three [11]. Moreover, there is also a positive correlation between IAP and autism-like behaviours. A cross-sectional study conducted in Shenzhen concluded that there was a significant positive dose-response relationship between the amount of cooking oil fumes (COF) exposure or cooking frequency during pregnancy and the likelihood of autism-like behaviours in preschool children [12]. A randomized controlled trial involving 540 pregnant women in Ulaanbaatar, Mongolia, conducted between 2014 and 2015 also concluded that increased indoor $PM_{2.5}$ concentrations during pregnancy caused by coal burning in household heating stoves were associated with higher scores on autism-related behaviours in children [13]. However, a cohort study in southern Sweden showed that although $PM_{2.5}$ exposure from small building heating was also associated with ASD, the association was less significant in the fully adjusted mode [14]. This may be due to the different backgrounds of different countries regarding this fuel, involving socio-economic factors, production requirements, lifestyle adjustments, etc [15].

Table 1 Characteristics of the selected papers on NDDs

Ref.	Location	Study type	Key findings
[10]	Guangzhou, China	C-S	Participants with COFs exposure had a higher ADHD index and higher odds of ADHD symptoms. (OR=2.33, 95%Cl: 1.48, 3.66; OR=1.36, 95%CI: 1.04, 1.74)

Ref.	Location	Study type	Key findings
[11]	Shenzhen, China	Cohort	In preschoolers, those with high household air pollutants exposure had a higher risk of hyperactive behaviours.
[12]	Shenzhen, China	C-S	There is a positive association between COFs exposure and autistic-like behaviours in child, with the AORs for "often" was 1.66 (95%CI: 1.42, 1.95) and for "always" was 2.29 (95%CI: 1.96, 2.67).
[13]	Ulaanbaatar, Mongolia	RCT	Over the course of the pregnancy, a 9.6 μg/m^3 increase in indoor $PM_{2.5}$ concentration was linked to a mean SRS-2 T-score increase of 1.8 units (95 %CI: 0.3, 3.2).
[14]	Scania	Cohort	$PM_{2.5}$ exposure from small residential heating was associated with ASD in the partially adjusted model (OR=1.22; 95%CI:1.08, 1.37), while in fully adjusted model, OR= 1.12 (95%CI: 0.94, 1.34)

Note: ADHD, attention deficit hyperactivity disorder; AORs, adjusted odd ratios; ASD, autism spectrum disorder; CI, confidence interval; COFs, cooking oil fumes; C-S, cross-sectional study; OR, Odds Ratio; PM, particulate matter; RCT, Randomized Controlled Trial; Ref., References; SRS-2 T-score, Social Responsiveness Scale, 2nd edition

Therefore, the number and focus of studies on the effects of IAP from indoor combustion or heating on NDDs are limited. Current studies focus primarily on common products produced by indoor combustion, such as $PM_{2.5}$. Most studies have shown its negative effects on children's attention and cognitive function. In addition to $PM_{2.5}$, other pollutants produced by indoor solid fuel use vary depending on the fuel [16]. Their impact on children's intellectual development also warrants more extensive research, and the study region should be expanded beyond China and Europe.

3 Cognitive impairment and neurodegenerative diseases

3.1 Cognitive impairment

Cognitive impairment refers to dysfunction of multiple aspects of cognition. A person with cognitive impairment often experiences difficulty in learning, remembering, focusing and decision making. Mild cognitive impairment (MCI) is common in the elderly and often regarded as the phase that lies between normal aging and dementia [3]. It was estimated to have a global prevalence of 19.7% and carry a great economic burden. For example, a study conducted in Germany estimated that the medical and formal care costs for MCI individuals were elevated by 85% compared to the healthy controls, and the mean healthcare costs per year were 8,795€ with a 95%CI of 6,200 to 11,391€ [17]. In addition, individuals in the United States progressing from MCI to Alzheimer disease and related dementia disorders experienced substantially higher medical costs than those with stable MCI [18], so it is important to early identify MCI and manage potential disease influencing factors. The main finding was that participants exposed to IAP from unclean fuel use had a higher risk of cognitive impairment, and the specific findings were discussed from the perspectives of exposure, outcome as well as potential influencing factors in this section.

The details of the selected articles were presented in Table 2. Regarding exposure, solid fuel use for cooking had adverse effects on cognition, but there is uncertainty in terms of heating and lighting. For example, a study showed that the association between solid heating fuel use and total cognitive score was not statistically significant during the follow-up, but the cross-sectional results in the same article was statistically significant [19]. In addition, two articles demonstrated low effect size in terms of solid heating fuel use [20,21]. This might be related to differences in exposure intensity and duration. Exposure to indoor air pollutants from cooking is more likely to be regular and long-term, resulting in a larger cumulative exposure. Heating tends to be seasonal (only in winter) and exposure to the generated pollutants is relatively low [19]. It is also worth noting that there is a study conducted in Ireland [21], there might be differences in socioeconomic factors (e.g., educational levels, culture and management of chronic diseases) between developed and developing countries, resulting in smaller effect size observed in study conducted in developed countries [15]. Further multi-national research is needed to determine the impact of solid heating fuel use on cognitive function. Moreover, an article showed that use coal for cooking can elevate the risk of cognitive decline [22], while another found such association in wood use but not coal use [23]. The potential reason is that China promoted improved coal-fuelled stoves in recent years, and such stoves was reported to be able to reduce the emission of coal burning pollutants [24]. The former study analysed data from 1997 to 2015 [22] and the latter used data from China Health and Retirement Longitudinal Study (CHARLS) wave 2011, 2013 and 2015 [23]. Participants from earlier cohort may be exposed to more indoor air pollutants from coal use because of using traditional stoves, and thus had a significant effect size. Furthermore, some literature also demonstrated the benefit of changing fuels from solid to clean [19, 22, 25, 26], especially switching cooking fuels. These findings indicated the great benefits of switching to improved stoves and cleaner fuels, which can not only mitigate the risk of cognitive decline among the elderly, and is potentially beneficial for the recovery of cognitive function because MCI can be slowed or partially reversed [27]. Finally, two articles measured exposure to specific pollutant and found that black carbon, particulate matter, NO_2 and O_3 can adversely affect cognitive health [28,29]. Although the number of participants were relatively limited (120 participants and 401 participants), but these research addressed the greatest uncertainty in most literature, which is the lack of significant information (e.g., temperature, humidity, exposure duration and frequency) and recall bias caused by measuring exposure through questionnaires. The design of these articles holds significant reference value for future research, and the details will be discussed in section 5.

In terms of the outcome, the literature we found explored the impact to specific domains of cognitive health in addition to the overall cognitive function. However, there is significant variation in the domains because there is not a universally accepted tool for cognitive function screening. The commonly explored domains were episodic memory, visuo-spatial function and attention. And the most frequently used tools were Mini-Mental State Examination (MMSE). In recent years, many systematic reviews were conducted to explore the sensitivity and specificity of different screening tools, and each tool has advantages and applicable scenarios [30,31]. It is necessary to develop a widely applicable screening tool, and we recommend using multiple tools in studies focusing on the association between environmental pollutant and cognitive function. In addition, some research investigated the effect of solid fuel use on multimorbidity. For example, a study conducted in 2024 employed data from CHARLS and identified physical-psychological-cognitive multimorbidity (PPC-multimorbidity) as the co-occurrence of physical illness (stroke, heart disease, hypertension, diabetes, lung disease, arthritis or cancer), depression and cognitive impairment. Their results suggested the adverse effects of using solid fuels and the benefits of changing to cleaner fuel [32]. Similarly, another research conducted in 2025 also analysed data from CHARLS and identified cognitive frailty (CF) as the co-occurrence of cognitive impairment and physical frailty. The results showed that participants using solid fuel for cooking or heating had a higher risk of CF, and those who changed from solid to clean fuel for cooking showed a decreased risk of CF [33]. These articles imply future research directions may be related to multimorbidity. It has an estimated global prevalence at 51% among the elderly, and the complex interactions among diseases also affect the vulnerability of the elderly [34]. Future research needs to dive deeper into multimorbidity related to cognitive impairments and the interaction among diseases.

There were also some influencing factors that may affect the association between IAP and cognitive health. The most frequent studied factor was gender, and the studies of developing countries demonstrated that females were more vulnerable. One explanation is that women in developing countries often bear responsibility of household chores such as cooking. Compared with males, their exposure from using solid fuel is characterized by longer duration and more regular frequency, and thus more exposure to indoor air pollutant [1]. Another explanation is that females might be more vulnerable to air pollutants such as particulate matter. $PM_{2.5}$ is an important product of indoor solid fuel combustion, and the neuroinflammation it induces serves as the potential mechanism of cognitive decline [35]. Previous mechanistic studies have demonstrated that females had greater susceptibility to neuroinflammation. For example, among rats exposed to $PM_{2.5}$ for 16 months, only female subjects exhibit elevated levels of interleukin-6 in the hippocampus. And the level of tumour necrosis factor-α increased in most brain regions in female but solely heightened in male hypothalamus [36]. However, it is worth noting that the study conducted in Ireland found contrary results [21]. The possible reason is that the focus of this article is on heating not cooking, and it is the only study conducted in developed European countries. There are sociocultural differences between different countries, which may result in relatively low exposure of indoor air pollutants for Irish women. In addition to gender, many relevant factors that may affect the association were also investigated, such as age, educational level, residence, lifestyle (e.g., physical activities, smoking history, drinking history), health condition (e.g., cardiovascular diseases, diabetes, depression, sleeping disorders), self-care ability and ventilation facilities. However, the research we discovered often applied logistic regression and regarded these factors as independent. Few studies have explored the interactions among these factors and their impact on cognition. One study is with relatively certain reference value regarding methodology [37]. The authors applied Lasso regression to select the potential factors and Bayesian networks to explore the dependencies among factors. And they found that indoor air pollution, age and educational level directly affect cognitive impairment in the older adults. Residence (rural/urban) can indirectly affect cognitive health through educational level or indoor air pollution, while the indirect influence of marital status was through age. In the future, more machine learning technologies should be applied to explore the interactions not only among factors but also between influencing factors and multimorbidity.

Table 2 Characteristics of the selected papers on cognitive impairment

Ref.	Location	Study Type	Key Findings
[19]	China	C-S and cohort	In the cross-sectional analyses, participants using solid fuel for cooking (β = –0.65; 95%CI: –0.85, –0.45) and heating (β = –0.39; 95%CI: –0.63, –0.16) had lower total scores of cognitive functioning. In the follow-up study, participants using solid cooking fuel had lower total scores of cognitive functioning (β = –0.24, 95%CI: –0.45, –0.04). Participants who switched from solid to cleaner cooking fuel had a lower degree of cognitive impairments.
[20]	China	Cohort	Participants using solid fuel for cooking (OR=1.11, 95%CI: 1.01, 1.23) and heating (OR=1.15, 95%CI: 1.01, 1.31) had a higher risk of MCI. Healthier lifestyle, especially healthier BMI, can reduce the risk.
[21]	Ireland.	Cohort	Participants using solid heating fuel had a higher risk of cognitive decline (b = –0.22, 95%CI: -0.37, –0.08, p = 0.003). There were statistically significant association observed in males, but not in females.
[22]	12 provinces in China	Cohort	The use of unclean fuel for cooking was negatively associated with global cognitive function (P<0.05), but the association between the use of unclean fuel for lighting and global cognitive function was not statistically significant (P>0.05). Participants switching from unclean to clean cooking fuel had a better global cognitive function. Hypertension was the potential mediator. Those who were female, ≥65 years, living in rural area and using coal for cooking were vulnerable group.
[23]	China	C-S	There was sex difference in the association between solid cooking fuel and cognitive impairment (P=0.008). Females were more vulnerable than males. Wood use was associated with cognitive decline in cooking and heating, and no such association was found in coal use.

Ref.	Location	Study Type	Key Findings
[25]	China and Mexico	Cohort	Participants using solid cooking fuel had a higher risk of cognitive decline in the cohort of CFPS, CHARLS and MHAS. Those who switch from solid to clean fuel showed a decreased risk of cognitive decline. Physical activity, diabetes, hypertension dyslipidemia and HDL-C were potential mediators.
[26]	China	Cohort	Participants using biomass cooking fuel had a higher risk of cognitive impairment and cognitive decline. Those who switched from biomass to clean cooking fuels had a lower risk of cognitive impairment and cognitive decline. The use of ventilation facilities, living with family members and having a regular exercise pattern can reduce the risk.
[28]	Two rural villages of Shanxi Province, China	C-S	There were positive associations between indoor PM_1, $PM_{2.5}$, PM_{10}, NO_2, O_3 exposure and the risk of cognitive impairment (for every 1μg/m^3 increase in PM_1, $PM_{2.5}$, PM_{10}, NO_2, and O_3, OR:1.070 (1.040–1.100), OR: 1.038 (1.022–1.054), OR: 1.028 (1.016–1.039), OR: 1.045 (1.007–1.084), OR: 1.021 (1.010–1.033), respectively). The female group is more vulnerable than male group.
[29]	Northern China	C-S	Overall cognitions were negatively associated with fine particulate matter exposure (-0.13, 95%CI: -0.22, -0.04) and black carbon exposure (-0.10. 95%CI: -0.19, -0.01). Attention was the cognitive domain that had the strongest association with the exposure.
[37]	China	C-S	The direct influencing factors of cognitive impairment in the older adults were age, educational level and IAP. Marital status and residence (rural/urban) were indirect influencing factors.

Note: BMI, body mass index; CFPS, the China Family Panel Studies; CHARLS, the China Health and Retirement Longitudinal Study; CI, confidence interval; C-S, cross-sectional study; HDL-C, high-density lipoprotein cholesterol; MCI, mild cognitive impairment; MHAS, the Mexican Health and Aging Study; OR, odds ratio; PM, particulate matter; Ref., references.

There were three systematic review and meta-analysis that investigate the relationship between IAP and cognition [38-40]. Their results all support that participants using solid fuel had a higher risk of cognitive impairment and switching to cleaner fuels can lower the risk. However, these studies shared similar limitations such as the small number of the included studies and high heterogeneity. Future epidemiological research should be conducted in more countries and focusing on specific indoor air pollutants, and meta-analysis should apply methods like Hartung-Knapp-Sidik-Jonkman (HKSJ) adjustment to deal with the substantial heterogeneity.

3.2 Neurodegenerative disorder

Mild cognitive impairment is also called as "preclinical dementia", it progresses to Alzheimer disease (AD) at the yearly rate of 10%-15% [3]. AD is a common neurodegenerative disorder (NDGD) and the most typical form of dementia, accounting for about 60% to 70% of dementia cases. From 1991 to 2021, the global prevalence of Alzheimer disease and other dementias (ADRD) increased by approximately 1.6 times among individuals aged 65 years and above, and the worldwide economic burden in 2019 was about 2.8 trillion dollars [41]. Parkinson disease (PD) is another NDGD, which is characterized by a maximal tremor at rest, mask-like facial expression, slow voluntary movements, rigidity, retropulsion and stooped posture. It was estimated that over 8.5 million people suffered from PD worldwide in 2019 [42] and the financial burden in the United States reached 51.9 billion dollars in 2017 [43]. In this review, we retrieved a total of 226 articles from PubMed, 6 met our selection criteria and were discussed in the following text. Noteworthy, we did not find any article directly investigating the association between AD and IAP, so we discussed studies on all-cause dementia to explore the potential effect of IAP on AD. Table 3 displayed the features of the selected studies.

Regarding the association between dementia and IAP, we found 5 studies, of which 3 was conducted in China [44-46]. They all analysed data from CHARLS and found that IAP increases the risk of dementia. Depression and accelerated biological age can influence the association. However, the remaining 2 articles had different findings [47,48]. They were both conducted in northern Sweden and the effect of IAP on dementia was uncertain. One study found that the association between dementia risk and 1μg/m^3 increase in $PM_{2.5}$ exposure from indoor wood burning was not statistically significant [47], while another reported that $PM_{2.5}$ from indoor wood combustion even might have a protective effect on dementia [48]. One potential reason is that these two studies were both conducted in the developed country, which has better socioeconomic status. As mentioned in section 3.1, factors such as educational level, lifestyle and health condition can affect the association between IAP and cognitive health. These factors may be more advantaged among the elderly in Sweden than those in China [15]. These brain-protective advantages may statistically mask the adverse effect of indoor air pollutants on dementia, which suggests the importance of studying more influencing factors and adjusting the residual confounders. Another reason is that using different fuels produce different pollutants with varying toxicities. The two studies in Sweden both investigated the $PM_{2.5}$ exposure from indoor wood burning [47, 48], while the other 3 studies did not mention the fuel type [44-46]. Taking $PM_{2.5}$ as an example, the toxicity of $PM_{2.5}$ from burning coal and burning biomass is different [16]. In terms of PD, the epidemiological evidence is very limited, and we only found 1 cross-sectional study conducted in Peru [49]. The study showed that the prevalence of PD is higher among those using wood cooking fuels. But the study used prevalence ratio as effect estimate, which does not capture incidence and not estimate disease risk.

In summary, the impact of IAP on dementia, AD and PD remains uncertain. The number of epidemiological research is very limited and further multinational investigations is needed to enrich our understanding.

Table 3 Characteristics of the selected papers on NDGDs

Ref.	Location	Study Type	Key Findings
[44]	China	C-S and retrosp-ective longitudinal analyses	In the cross-sectional study, participants using solid cooking fuel had a higher risk of dementia (OR = 1.22, 95%CI: 1.02, 1.47). Similar results were observed in the retrospective longitudinal analysis (OR = 1.44, 95%CI:1.06, 1.96). Depression partially affects the correlation between solid cooking fuel use and the risk of dementia.
[45]	China	Cohort	Participants using solid fuels for cooking or heating had a higher risk of dementia. The vulnerable group were females and those living in rural areas.
[46]	China	Cohort	Compared with those consistently using cleaner fuels, participants consistently using solid fuels had a higher risk of dementia (HR = 1.32, 95 % CI: 1.06, 1.64). Accelerated biological age partially affect the association between consistent solid fuel use and dementia.
[47]	Umeå, Northern Sweden.	Cohort	For every 1μg/m^3 increase in $PM_{2.5}$ exposure from indoor wood burning, the increasing risk of dementia was not statistically significant (HR=1.55, 95%CI: 1.00–2.41, p = 0.05).
[48]	Northern Sweden	Cohort	Exposure to $PM_{2.5}$ from indoor wood burning was negatively associated with dementia risk.
[49]	Northern Peru	C-S	Participants using wood as cooking fuels had a higher prevalence of Parkinson disease (PR = 3.45; 95%CI: 1.25; 9.48).

Note: CI, confidence interval; C-S, cross-sectional study; HR, hazard ratio; OR, odds ratio; PM, particulate matter; PR, prevalence ratio; Ref., references.

4 Mental disorders

Depression and anxiety are two most typical mental disorders. Depressive disorder (also known as depression) refers to prolonged low mood or loss of happiness or interest in activities, which are caused by the complex interaction of social, psychological and biological factors [50]; anxiety patients feel excessive panic or concern about certain specific situations [51]. These two mental disorders have become a major burden on global public health. According to WHO, approximately 280 million people worldwide suffer from depression, and up to 2019, 301 million people were suffered from anxiety disorder, the global financial burden of depression and anxiety is US$ 1 trillion each year [50, 51]. Table 4 showed the characteristics of the selected articles.

In terms of study design, we found that solid fuel exposure was mainly defined through self-reported fuel types in questionnaires, while depressive and anxiety symptoms were primarily assessed using screening tools such as Centre for

Epidemiological Studies Depression scale (CES-D) (12 studies), Patient Health Questionnaire (PHQ) (4 studies), and Generalized Anxiety Disorder (GAD) (5 studies). Overall, the key findings appear high consistency, indicating a positive association between solid fuel use and symptoms of anxiety and depression. However, when solid fuels were used only for heating purposes, no significant association was observed [52]. Vulnerable groups such as women, the elderly, rural residents, low-income populations, and individuals with low educational levels were found to be at a higher risk.

One of the earliest exploratory studies in this field was conducted in 2012 [53], despite its significant limitations, we consider that this paper remains highly valuable for research purposes: its cross-sectional design precludes the establishment of causality, and residual confounders such as unmeasured social stress may partially explain the effect size; the study was restricted to rural women of childbearing age in eastern India, and the measurement of depression outcomes relied on self-report screening tools. Nevertheless, the finding was moderate effect size and it still provides an important hypothesis foundation for subsequent research. Unlike recent papers, its data were recruited from volunteer rather than secondary analysis of large-scale cohort study data, and it preliminary explored depression related biomarker associations. We believe the core value of this paper lies in proposing hypotheses and paving the way for future study design.

Table 4 Characteristics of the selected papers on mental disorders

Ref.	Location	Study type	Key findings
[52]	China	Cohort	The use of solid fuels for cooking was associated with an increased risk of depression (HR=1.12, 95%CI: 1.02, 1.24), while heating alone showed no significant association. Combined use for heating and cooking was associated with higher risk (HR=1.15, 95%CI: 1.01, 1.31).
[53]	Eastern India, rural areas	C-S	The use of solid fuels significantly affected the risk of depression (OR=1.67, 95%CI: 1.18, 2.95).
[54]	Henan, China	C-S	Solid fuel use was associated with increased risks of depression (OR=1.237, 95%CI: 1.041, 1.469) and anxiety (OR=1.384, 95%CI: 1.153, 1.662). Longer cooking time was linked to higher risks of depression and anxiety, particularly in households without ventilation.
[55]	Henan, China	Cohort	The use of solid fuels was associated with an increased risk of depression (OR=1.46, 95%CI: 1.12, 1.89) and anxiety (OR=1.45, 95%CI: 1.10, 1.89).
[56]	Oaxaca, Mexico	C-S	The study showed higher risk of depression among women, participants aged 60 and above, those living in rural areas, and people using wood or charcoal for cooking.

Note: CI, confidence interval; C-S, cross-sectional study; HR, hazard ratio; OR, odds ratio; Ref., references.

The common limitation is the insufficiency in controlling confounding factors. Depression and anxiety are mental disorders caused by multiple factors that involve complex interactions among genetic, environmental, and social levels. We identified several key confounding factors, which should be incorporated into future research: socioeconomic status (SES), living environment, ventilation conditions, chronic diseases, and exposure to second-hand smoking. Among these factors, ventilation condition plays an important role. Although most of the studies we found accounted for ventilation, many did so insufficiently by simply asking participants about its presence without distinguishing between mechanical and natural ventilation. However, some papers still partially explored the moderating role of ventilation conditions. For instance, one study presented that mechanical ventilation may eliminate the risk of depression associated with solid fuel use and prolonged cooking (OR reduced from 1.54 to 1.02), whereas natural ventilation does not provide such protective effects [54]. Another prospective cohort study found that 46% of the depression and anxiety risk could be attributed to the synergistic effect of using solid fuels and natural ventilation [55]. This finding implies that ventilation is not only an important confounding factor, but also an intervenable effect-modifying factor.

We also found that most papers reached the result of small effect size. Noteworthy, one study reported an extraordinary OR value of 12.192 (95%CI: 12.064, 12.321, $p < 0.001$) in the subgroup analysis of the elderly population [56]. The authors did not directly explain the cause of this abnormal value, but implied that it may be due to the elderly population were exposed for a longer time, hence increasing the risk. One possible reason is that the study ignored some key confounding factors in the older population, such as chronic disease conditions and disabilities. Another reason is that the categorization of the elderly was inadequate in this study. In the subgroup analysis, the older population was simply categorized as those aged ≥60 years. But relatively younger elderly people tend to have more resistance than the older elderly. Older elderly individuals may have a higher risk of depression due to health decline and longer exposure time [57], which may lead to the effect size of this subgroup were amplified. In addition, the possible reasons for the small effect sizes are as follows. Almost all papers measured anxiety and depression outcomes through screening tools such as CES-D and GAD, which may result in non-differential misclassification bias. Since the possibility of each participant being misclassified is the same, this will bias the effect estimate towards the null, resulting in a systematic underestimation of the association strength. Further studies should verify the results of screening tools through a more rigorous outcome definition (e.g., International Classification of Diseases, ICD codes) to lower the non-differential misclassification bias. If screening tools are the only way to measure outcomes, a quantitative bias analysis should be included to measure the magnitude of underestimation of the effect size [58].

In conclusion, despite the association between household solid fuel or biomass fuel use and depression and anxiety is notable, current studies are designed based on secondary analysis of large-scale cohort database, and the results of these studies should be interpreted cautiously. Future research should include biomarker detection in the study design, longer-term cohort studies should also be considered to further enhance the credibility of the evidence.

5 Research limitations

Although the number of studies focusing on cognitive impairment and mental health disorders is relatively large, we need to interpret our findings with caution. This is because these articles suffered from the issue of formulaically analyse big health data sets, especially in the field of cognitive impairment and mental health disorders. This has been criticized many times this year [59,60]. Big health data set such as CHARLS and Longitudinal aging study in India (LASI) contains a wealth of health-related measurements and involves a large number of participants, but it often leads to incomplete information when it comes to analysing specific health problems.

First, the common limitation of these studies is the self-reported exposure data. The studies often depend on the investigation of fuel type and stove use to determine exposure, lacking crucial data (e.g., exposure frequency, ventilation, humidity and temperature) and inevitably induce recall bias. Contents that remain uncertain include the interaction effect of household fuel use and outdoor air pollution, as well as the impact of mixed using clean and solid fuel during fuel transition. Another common limitation is that there might be residual confounding. Although previous studies indicated that factors such as health conditions and self-rated health can affect the association between IAP and neurological diseases, some big health data set do not measure this type of information. Regarding outcome determination, many studies used screening tools (e.g., CES-D and the abbreviated Community Screening Instrument for Dementia) rather than diagnostic criteria, resulting in misclassification. However, some studies have also attempted to address these deficiencies and these study designs have great reference value. For example, one study provided detailed descriptions of the methods for measuring personal exposure to specific pollutants and checking the compliance of the participants [29]. Another research not only measured specific indoor air pollutant exposure but also analysed microbiota from the fecal sample. The authors found that cognitive impairment was associated with air particulate exposure through microbiota gut-brain axis [28]. In addition, some researchers performed brain MRI to 994 participants and found females using polluting cooking technology had lower hippocampus volumes [61]. Furthermore, the number of the studies with a cross-sectional design is greater than that of longitudinal design. For example, in the studies focusing on cognitive impairment, 1 article presented both cross-sectional and follow-up results, 15 articles were cross-sectional studies and 9 were cohort studies. In addition, among the 21 studies focusing on mental disorders, only 4 utilized a cohort design. But cross-sectional survey can only identify association not causality and there might also be reverse causation. For instance, participants with lower cognitive function or mental health problems may be less likely to choose or switch to use clean fuel. Lastly, we also found that most research was carried out in developing countries with a focus of solid cooking fuel use, especially in China and India. Among the 25 research on cognitive impairment, 15 were conducted in China and 9 in India. Similarly, of the studies on mental disorders, 16 were carried out in China and 2 in India. But developed world also face the problem of using solid heating fuel, and more research should be conducted exploring its impact on neurological disease.

In summary, present studies provide information for the design of future cohorts specifically exploring this research problem, and scholars should pay attention not to produce similar articles based on big health data sets.

6 Policy analysis

According to WHO, 1.8 billion people worldwide will be unable to access clean fuels and technologies by 2030 if there are not policy intervention, so policy reform is crucial [1]. In the following texts, we analyse the policy approaches and current challenges for household energy and stoves in developing and developed countries.

Developing countries have made efforts in policy implementation and achieved success. In China, efforts originated in the early 1980s. The National Improved Stoves Programs (NISP) introduced 180 million improved stoves with chimneys [62]. From 2017 to 2021, the Clean Winter Heating Plan was implemented in northern China and encompassed more than 200 million residents living in rural areas [63]. However, wealthier areas and households transferred to clean fuels and stoves at a faster pace, while the most disadvantaged areas even saw a regression from clean fuels back to solid fuels. Similar problems were observed in India. Recent research has shown that despite the Pradhan Mantri Ujjwala Yojana (PMUY) increasing the connection rate of liquefied petroleum gas (LPG) to over 95%, nearly 85% of households mixed use LPG and solid fuels [64]. The factors that affect acceptability include the affordability of clean fuels and improved stoves, as well as cultural preferences (e.g., Traditional meals cooked with solid fuels tastes better). Therefore, the policy priority in developing countries should be on long-term financial supports on fuel supply as well as awareness campaigns such as community education programs [65].

The efforts of developed countries mainly focus on the wood burning appliances. The U.S. Environmental Protection Agency (EPA) sets New Source Performance Standards (NSPS), which are the federal standards for residential wood heaters. Manufactures of household wood heaters must be certified by EPA before they can sell the heaters in the U.S. In addition, there is 26% Federal tax credit for wood heaters and EPA provides guidance for community-level changeout programs for wood burning. However, a report pointed out the challenges in heater testing and standard enforcement, which result in some of the wood heater sold in the U.S. emitting air pollutants that exceed the standards [66]. The boldest policy is in the Australian Capital Territory (ACT), with the Cabinet's pledge to eliminate wood heaters by 2045. Although this policy seems to have encountered political resistance recently [67], the repetition and debate of the "phase-out agreement" have attracted political and public attention, which are also a manifestation of progress. In addition to policies on wood burning appliances, developed countries tried to formulate and implement laws and regulations on switching gas to electric stoves. For example, the New York State in the U.S. updated its building code this year, which bans using gas equipment in the majority of new buildings [68]. From the perspective of the health impact of fuel, research showed that using gas increased the risk of COPD and pneumonia comparing to using electricity [69]. However, researchers from the same study also reported that using gas can reduce various health risks compared with using solid fuels. Therefore, it is appropriate for developing countries to use gas as a transitional fuel to reduce the disease burden.

In short, both developing and developed countries have made efforts in policy related to the switch of household cleaner fuels. The main challenges include standard enforcement, political resistance, energy poverty and social inequities. Policy makers should pay attention to efficient economic subsidy measures, educational materials tailored to specific cultural backgrounds, and stakeholder (e.g., expert panels, public health advocators, traditional energy industry) communication. These policies are beneficial for improving both indoor and outdoor air quality, as well as reducing related health risks.

7 Conclusion

Overall, we conclude that the impact of IAP from using solid fuels on NDDs and NDGDs remains uncertain due to the limited research number, and those using unclean fuel generally had a higher risk of cognitive impairment and mental disorders. The common limitation of the studies we found is the formulaic analysis of big health datasets, and the results should be interpreted with caution because the analysis was based on incomplete information. Long-term cohorts, specific indoor air pollutant exposure measurements and biomarker detection should be prioritized in the future research design. Developing countries should promote phasing out solid fuel and the renewal of improved stoves, and the developed countries should pay more attention to policies on wood heating. Efficient economic subsidy measures and public education adapted to specific cultural backgrounds are recommended policy instruments for both developing and developed countries.

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