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Does Human Capital Impact Clean Cooking Fuel? Evidence From BRICS Nations

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This study examines the impact of human capital on the adoption of clean cooking fuel in BRICS nations during the period 1990–2023. Utilizing several panel data tests, the findings indicate that human capital enhances the use of clean cooking fuels in BRICS countries. Furthermore, women's economic empowerment and GDP per capita have a positive effect on clean cooking fuel adoption. These results underscore the importance of human capital, GDP per capita, and women's economic empowerment in advancing inclusive and sustainable energy practices across BRICS nations.

I. Introduction

Access to clean cooking fuel remains a significant developmental challenge in many emerging economies. Among BRICS nations, despite economic growth and increasing urbanization, a substantial portion of the population still relies on traditional biomass fuels such as firewood, cow dung, and crop residues. These fuels contribute to indoor air pollution, deforestation, and various adverse health effects, particularly among women and children who spend significant time in cooking environments (Baqir et al., 2024). Several initiatives such as the national clean cooking fuel program, rural electrification programs, gas distribution network expansion, the national biogas and manure management program, and the Pradhan Mantri Ujjwala Yojana have been implemented. Still, 2.3 billion people, one-third of the global population, open fires or inefficient stoves, causing household air pollution that leads to 3.2 million annual deaths, including 237,000 child fatalities (Puthumana et al., 2021; World Health Organization, 2016). Low preference in BRICS nations for clean fuel is a matter of concern in achieving SDG 7 due to low affordability, especially in rural regions (Swain & Mishra, 2020). Moreover, BRICS countries, comprising over 40% of the world's population and nearly one-third of global energy consumption, represent a vital group of emerging economies facing the dual challenge of promoting sustainable growth while tackling energy poverty. Thus, examining the relationship between human capital and access to clean cooking fuels in the BRICS nations provides insights into how investments

in education and skill development can accelerate the transition toward cleaner and more inclusive energy systems.

At the global level, the shift to cleaner fuels, such as liquefied petroleum gas (LPG), electricity, and biogas, has been closely associated with improvements in income, infrastructure, and household characteristics. Yet, literature suggests that human capital, beyond mere income or educational attainment, can play a critical role in influencing household energy behavior, including cooking fuel choices. This encompasses not only formal education but also cognitive and non-cognitive skills, which influence decision-making capacity, environmental awareness, and the ability to navigate fuel markets or subsidy schemes (Bai et al., 2024).

While some country-specific studies have examined the linkage between human capital and energy transition—for example, the role of cognitive and non-cognitive skills in fuel adoption in rural China (Bai et al., 2024), and the educational effect of fuel usage in rural India as examined by Biswas and Das (2022). Another study by Haider et al. (2024) identified a positive association between educational attainment and clean cooking fuel in Uttar Pradesh. Biswas and Das (2022) also investigated the impact of household cooking fuel choices on educational outcomes in India. However, there is a notable lack of cross-national evidence in BRICS nations despite the ongoing problem of insufficient access to clean cooking fuel in these countries. Additionally, previous studies have considered the educational level as a proxy for human capital, which may not be a fully adequate measure (Bai et al., 2024). Another limitation of

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earlier research is the lack of focus on the role of women's economic empowerment.

Considering the distinctive challenges and opportunities for comprehensive analysis within BRICS countries, examining the impact of human capital on clean cooking fuel is imperative due to the ongoing problem of insufficient access to clean cooking gas. Understanding how human capital influences the choice of clean cooking fuel is crucial for BRICS nations in designing targeted interventions. As a result, this study contributes to the current body of literature in three ways. First, existing studies, such as Biswas and Das (2022), Bai et al. (2024), and Haider et al. (2024) focus on single countries, with little comparative work exploring BRICS nations as a group. This limits understanding of the shared and context-specific challenges within these influential economies. To address this gap, we expand our research to the BRICS nations in this study. Second, previous research often used educational attainment as the only indicator of human capital, which is considered a narrow proxy by Bai et al. (2024). Thus, this study supplements earlier work by utilizing the comprehensive human capital proxy provided by the Penn World Table (Feenstra et al., 2015), which encompasses both average years of schooling and the return to education. This approach provides more accurate and reliable insights into the relationship between educational attainment and access to clean cooking fuel. Third, although women are disproportionately affected by household air pollution and typically act as primary cooks, few studies disaggregate the impact of women's economic empowerment on clean fuel transitions, and there remains inadequate focus on gendered dimensions. Therefore, this study highlights the significant role of women's economic empowerment in promoting sustainable development and improving public health by adopting cleaner energy solutions for cooking.

The findings of this study, based on several panel data models, reveal that human capital has a significant impact on the adoption of clean cooking fuels in BRICS countries. Furthermore, women's economic empowerment and higher GDP per capita are found to have a positive influence on the use of clean cooking fuels.

This paper is organized as follows: Section II outlines the methodology and data sources. Empirical results are detailed in Section III. Finally, Section IV presents conclusions and summarizes the key findings.

II. Methodology and Data

To determine whether error correlation exists between individual cross-sections in panel data, this study first applies the cross-sectional dependence (CD) test. Panel data often exhibits cross-sectional dependence due to common shocks, unobserved components, spatial dependence, and idiosyncratic pairwise correlations in the disturbances (Pe-

saran, 2021). These are considered possible causes of CD in panel data.

After checking for CD, this study applies fixed or random effects models based on the Hausman test's results. Furthermore, to ensure the robustness of the results, the feasible generalized least squares (FGLS), fixed effects model with Driscoll-Kraay standard errors, and panel corrected standard errors (PCSE) are employed, providing unbiased and efficient estimates by addressing heteroscedasticity and autocorrelation issues in the error terms. Thus, we estimate the following model:

$$\ln ACFTFC_{it} = \beta_0 + \beta_1 \ln HC_{it} + \beta_2 \ln GDP_{it} + \beta_3 FWASW_{it} + \beta_4 INF_{it} + \varepsilon_{it} \quad (1)$$

where, $\ln ACFTFC$ denotes natural logarithms of access to clean fuels and technologies for cooking, $\ln HC$ natural logarithms of indicates the human capital index, $\ln GDP$ denotes the natural logarithms of GDP per capita, $FWASW$ indicates the female wage and salaried workers, INF represents inflation rates, and ε_{it} represents the error term, respectively. The selection of the independent variables is based on existing literature (see, for instance, Li et al., 2024; Vicent et al., 2025). It has been argued that a country with improved human capital enhances access to clean cooking fuel through increased awareness and higher income, leading to better decision-making in adopting clean cooking fuel (Li et al., 2024). Vicent et al. (2025) state that greater women's economic empowerment is more likely to enhance financial autonomy and improve access to clean cooking. Murshed (2025) discusses the role of inflation in accessing clean cooking gas. This study collects data from various sources spanning 1990 to 2023¹. $\ln ACFTFC$ is obtained from the World Health Organization (WHO). The independent variables are $\ln HC$, $\ln GDP$, $FWASW$, and INF . Data for GDP , $FWASW$, and INF are sourced from the World Development Indicators (WDI), while HC is obtained from the Penn World Table (PWT 11.0).

Table 1. Variable description and data source

Variables	Description	Data Source
$\ln ACFTFC$	Natural logarithms of access to clean fuels and technologies for cooking	WHO
$\ln HC$	Natural logarithms of human capital	PWT 11.0
$\ln GDP$	Natural logarithms of GDP per capita (constant 2015 US\$)	WDI
$FWASW$	Wage and salaried workers (% of female employment)	WDI
INF	Inflation, GDP deflator (annual%)	WDI

Note: This table provides details on all data used in this study.

¹ The selection of the sample period is based on data availability.

III. Empirical Results

This section begins with a summary of descriptive statistics and the results of the CD test. Table 2 reports the mean values for $\ln ACFTFC$, $\ln HC$, $\ln GDPPC$, $FWASW$, and INF as 4.14, 0.87, 8.33, 61.42, and 74.96, respectively, each exhibiting varied ranges. The standard deviations are generally large, except for HC , indicating substantial variability within the sample. The results of the Pesaran test, as shown in Table 2, confirm the presence of cross-sectional dependence, which justifies the use of FGLS. Therefore, pooled ordinary least squares estimation is inappropriate due to the identified cross-sectional dependence.

Table 2. Descriptive statistics

Variables	$\ln ACFTFC$	$\ln HC$	$\ln GDPPC$	$FWASW$	INF	
Mean	4.14	0.87	8.33	61.42	74.96	
Median	4.35	0.87	8.67	67.96	75.50	
Maximum	4.61	1.21	9.43	99.48	2736.97	
Minimum	2.42	0.40	6.28	9.30	0.001	
Std. Dev.	0.53	0.21	0.86	29.54	342.48	
Skewness	-1.27	-0.06	-0.98	-0.52	170	
Kurtosis	3.96	2.10	2.69	1.75	48.69	
Jarque-Bera	52.53*** (0.00)	5.79* (0.06)	27.76*** (0.00)	15.55*** (0.00)	10352.46*** (0.00)	
Observations	170	170	170	170	5	
Pesaran CD	-2.91*** (0.004)					

Note: This table presents the results of descriptive statistics, a cross-sectional dependency test, and a heteroskedasticity test. *** indicates statistical significance at 1% level. *p-values are provided in parentheses.

The baseline results are presented in Table 3. The null hypothesis favoring the fixed effects model is rejected by the Hausman test, as the p -value is lower than 0.05. The results of the fixed effects model reveal significant roles for $\ln HC$ and $\ln GDPPC$ in determining $\ln ACFTFC$. Notably, HC and $GDPPC$ are both statistically significant and show a positive relationship with $\ln ACFTFC$, a 1% increase in $\ln HC$ is associated with a 0.695% rise in access to clean cooking fuels. These findings are consistent with Bai et al. (2024) and Li et al. (2024). Similarly, we find that a 1% increase in $\ln GDPPC$ leads to a 0.407% increase in $\ln ACFTFC$. Additionally, our results show that a higher level of $\ln HC$, which includes education and skills, leads to better job and income opportunities, thereby encouraging the adoption of clean cooking technologies by making them more accessible and affordable (Gould et al., 2020). This finding aligns with Gould et al. (2020), who also note that education is crucial for increasing awareness about the health benefits of clean cooking fuels. Furthermore, individuals with higher educational attainment and skills are better informed about the risks associated with traditional cooking methods (Haider et al., 2024). Additionally, $FWASW$ enhances $\ln ACFTFC$, with a 1% increase in $FWASW$ resulting in a 0.013% increase in $\ln ACFTFC$. This suggests that the economic empowerment of women increases their decision-making power, which in turn promotes greater adoption of clean cooking fuels. Moreover,

inflation is also found to be statistically significant, highlighting its important role in influencing $\ln ACFTFC$ by stimulating economic activities that contribute to rising income levels. Overall, the study's findings emphasize the significance of $\ln HC$ and $FWASW$ in facilitating access to cleaner cooking methods.

Table 3: Fixed effect model and FGLS

Variable	Fixed effect model	FGLS
$\ln HC$	0.695*** (0.166)	0.555*** (0.100)
$\ln GDPPC$	0.323*** (0.055)	0.252*** (0.0285)
$FWASW$	0.013** (0.001)	0.0047*** (0.001)
INF	0.00012*** (0.0001)	0.00001 (0.00001)
Constant	0.033 (0.278)	1.243*** (0.193)
Observations	170	170
Hausman Test	48.69*** (0.00)	...
R-squared	0.901	...
Number of countries	5	5

Note: ***, **, and * indicate the statistical significance at 1%, 5%, and 10% levels, respectively. Standard errors are reported in parentheses.

Next, to conduct a robustness check and address issues of heteroscedasticity and cross-sectional dependence, we employ the FGLS and PCSE tests. The results from FGLS, presented in Table 4, are consistent with the fixed effects model except for $FWASW$. Additionally, the study uses a fixed effects model with Driscoll-Kraay standard errors and the PCSE test to further verify the robustness of the model.

Table 4. Fixed effect (Driscoll-Kraay standard errors) and panel-corrected standard errors estimation

Variable	Fixed effect (Driscoll-Kraay standard errors)	PCSE
<i>lnHC</i>	0.693** (0.300)	0.762*** (0.0985)
<i>lnGDP</i>	0.324*** (0.0392)	0.332*** (0.0313)
<i>FWASW</i>	0.0129 (0.00996)	0.00213* (0.00117)
<i>INF</i>	0.000117*** (0.0000382)	0.00000562 (0.00000709)
Constant	0.0333 (0.193)	0.565** (0.244)
Observations	170	170
<i>R</i> -squared	0.73	0.97
Number of countries	5	5

Note: ***, **, and * indicate the statistical significance at 1%, 5%, and 10% levels, respectively. Standard errors are reported in parentheses.

IV. Conclusion

This study investigated the impact of human capital on access to clean cooking fuel in the BRICS nations, using data from 1980 to 2023. To do so, various panel data models

were employed. The results showed that human capital has a significant impact on access to clean cooking gas. Based on our findings, several specific policy recommendations are suggested. First, BRICS countries should integrate clean energy awareness and household energy management modules into vocational and technical training programs to link skill development with sustainable energy use. Second, increasing women-focused microfinance and entrepreneurship programs can help stimulate investments in clean cooking technologies, thus supporting both gender empowerment and the energy transition. Third, targeted subsidies or tax incentives for households utilizing clean cooking fuels, coupled with educational efforts highlighting health and environmental advantages, might expedite behavioral transformation. Finally, improving health and education facilities, especially in rural and low-income regions, may indirectly enhance individuals' ability to make informed energy decisions. These measures not only enhance access to clean energy but also align with the objectives of SDG 5 (Gender Equality) and SDG 7 (Affordable and Clean Energy), thereby fostering sustainable and inclusive development in the BRICS economies.

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