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Policy trade-offs between climate mitigation and clean cook-stove access in South Asia

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Household air pollution from traditional cook stoves presents a greater health hazard than any other environmental factor. Despite government efforts to support clean-burning cooking fuels, over 700 million people in South Asia could still rely on traditional stoves in 2030. This number could rise if climate change mitigation efforts increase energy costs. Here we quantify the costs of support policies to make clean cooking affordable to all South Asians under four increasingly stringent climate policy scenarios. Our most stringent mitigation scenario increases clean fuel costs 38% in 2030 relative to the baseline, keeping 21% more South Asians on traditional stoves or increasing the minimum support policy cost to achieve universal clean cooking by up to 44%. The extent of this increase depends on how policymakers allocate subsidies between clean fuels and stoves. These additional costs are within the range of financial transfers to South Asia estimated in efforts-sharing scenarios of international climate agreements.

Three billion people globally burn solid fuels such as firewood, charcoal, coal, dung, and crop residues in open fires and traditional stoves for cooking and heating[1]. Household air pollution from the incomplete combustion of these fuels globally leads to 4.3 million premature deaths each year, with 1.7 million of those in South Asia. This exceeds the burden of disease from any other energy-related or environmental risk factor[1–4]. Solid-fuel use also perpetuates income and gender inequality by forcing users, mostly poor women and children, to spend long hours collecting fuels and to suffer from its adverse health effects. To address this problem, the United Nations Secretary-General's Sustainable Energy for All (SE4All) initiative and the new Sustainable Development Goals aim to achieve universal access to modern energy services by 2030 (refs 5–7).

Numerous intervention efforts have focused on distributing more efficient and cleaner burning biomass stoves, but several of these programmes have had little or no demonstrable impact on health outcomes[3,8]. In India, the nation with the largest population of solid-fuel users globally[5], government interventions have sought to make petroleum-based fuels, such as kerosene and liquefied petroleum gas (LPG), more affordable through subsidy at an estimated cost of over US$6 billion per year[9]. Although LPG use has grown rapidly, particularly in rural areas[10], over 72% of Indians continued to rely primarily on solid fuels in 2012 (refs 2,11).

In the future, expanding clean cooking may become more challenging if climate policies increase the cost of fuels[12,13]. Previous research has found that greenhouse gas (GHG) emissions reductions in Asia[14,15] and Africa[16,17] would increase the cost of kerosene and LPG. However, these studies do not explore compensatory policies that could counteract these effects, and assess only a limited set of climate mitigation scenarios. Only two studies explore normative scenarios that achieve access and climate goals simultaneously[18,19], both of which do not explore the cost-effectiveness or distributional impacts on population subgroups of these policies. Meanwhile, studies that have evaluated the cost-effectiveness of energy access policies[20,21] have not considered the impact of climate policy. The latest assessment of the Intergovernmental Panel on Climate Change (IPCC) concludes that we have only low confidence in our understanding of the possible impacts of climate policy on access to modern energy services, and medium confidence in the policies needed to counteract them[13].

In this study, we contribute new insights to the interaction of climate policy and clean cooking access policies by quantifying the feasibility and costs of achieving universal access by 2030 for a range of climate policy stringencies, and under a wide range of fuel and stove price support policies. Our analysis suggests that the potential trade-offs between the two goals might be larger than suggested by previous studies. However, we find that efficient policy design could partially compensate for the additional access policy costs associated with climate mitigation. Furthermore, these costs fall below the level of potential financial transfers to South Asia that may result from international climate agreements.

Climate and access policy scenarios

In what follows, we define clean cooking as cooking with all non-solid fuels such as LPG, electricity, piped gas and kerosene. Improved biomass cooking stoves (ICS) are not considered clean cooking owing to ongoing concerns about whether they yield significant health benefits[22–24]. Therefore, we include ICS in our analysis, but count only modest incremental benefits over traditional biomass stoves. We use the MESSAGE-Access household fuel-choice model to quantify clean cooking uptake, cost of access policies, and the associated health outcomes under different climate mitigation scenarios[20,21,25] (see Methods and Supplementary Methods).

We focus our analysis on South Asia[26] because it has the greatest number of solid-fuel users globally[2,5]. MESSAGE-Access models four distinct demographic groups categorized by rural/urban location, to account for differences in the availability of cooking fuels; and daily per-capita expenditure, to account for differences in the affordability of fuels. We henceforth refer to these categories as R1 and R2 for rural and U1 and U2 for urban groups. Expenditure categories are set at less than and greater than PPP$2 per day and PPP$5 per day in rural and urban areas, respectively (PPP, purchasing power parity). The difference reflects the fact that the average expenditure of urban households in India has historically been roughly double that of rural households, and continues to grow[27].

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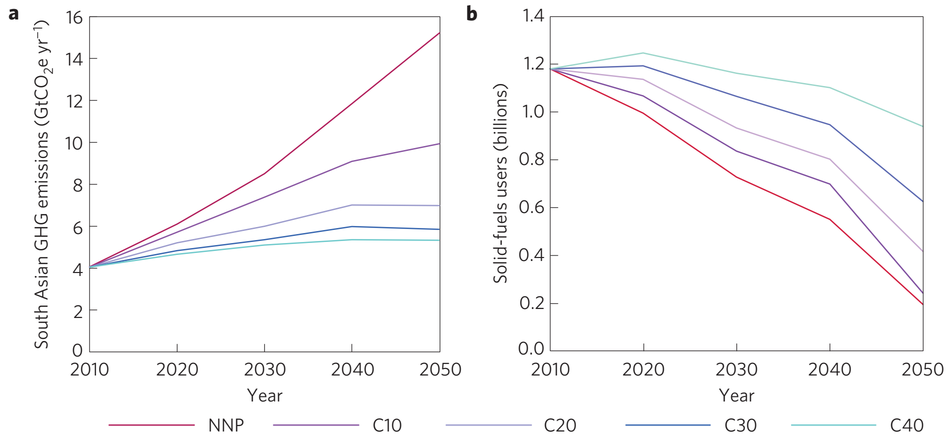

Figure 1 | South Asian emissions and solid-fuel reliance under baseline and climate mitigation scenarios. a, GHG emissions from the MESSAGE South Asia region. **b**, Solid-fuel users in billions from 2010 to 2050. Results are given for a baseline (NNP) and four increasingly stringent climate mitigation scenarios (C10, C20, C30, C40).

MESSAGE-Access allocates each group's energy needs across fuel-stove options in accordance with their preferences and financial means. We model fuel choice at the household level between LPG, kerosene, electricity, piped gas, and solid fuels burned in either traditional or improved stoves (see Supplementary Methods). Households typically stack multiple fuel-stove options to meet different cooking needs or as a strategy to cope with unreliable fuel availability and price[3,19]. Following recent trends evident in survey data[28], we assume households prefer to meet primary cooking needs with cleaner burning and more convenient options such as LPG, electricity, or piped gas (referred to as Tier 1), but may still use kerosene (Tier 2) and/or solids (Tier 3) in accordance with their budgetary constraints and preferences (see Methods and Supplementary Methods).

We use the Global Energy Assessment's Mix scenario[29] (GEA-M) as a baseline for this analysis—referred to as the no new policy scenario (NNP). We explore four GHG mitigation scenarios of increasing stringency, implemented as a carbon price of US$10 (C10), US$20 (C20), US$30 (C30), and US$40 (C40) per ton CO_2 equivalent in the year 2020, with the price rising at the social discount rate through until the end of the century (Supplementary Methods). Note that the resulting energy price outcomes could also be achieved via a wide range of alternative policy mechanisms that induce technology and fuel shifts to low/no carbon options[30,31]. When assessed with a probabilistic carbon cycle and climate model[32–35] (Methods), our climate policy scenarios are consistent with limiting a global temperature increase to no more than 2 °C relative to pre-industrial levels by 2100 with increasing probability of achievement (from a quarter to up to two-thirds). Our most stringent scenario represents a 66% probability of achieving this target.

We also model counteracting price support policies on clean fuels (0–75%) and stoves (0–100%), which may in practice be implemented through a range of policy instruments (see Supplementary Methods). We model these access policies with and without climate policy. Here, we present only policies supporting LPG, as we found this to be the cheapest among Tier 1 fuel-stove options. However, similar policies might well be implemented on other clean fuel-stove options. Consistent with present institutional conditions, we assume no administrative and implementation capacity to target these support policies to specific population subsets on the basis of household expenditure. All supporting policies are thus applied and available to all households in the same way. This is consistent with the approach of the Indian government, which introduced a new direct benefit transfer scheme for domestic LPG consumers to help reduce leakage and corruption, but did not target any specific household group[36].

Climate policy impacts on emissions and solid-fuel use

Projecting recent trends, including current energy and climate policies (NNP), South Asian GHG emissions rise rapidly throughout our model time frame, roughly doubling every 20 years (Fig. 1a). This baseline emissions trajectory matches reference scenarios in Indian national modelling studies that model high (7–8%) GDP growth and conservative low-carbon policies[37]. This growth and urbanization enable almost 1 billion people (63% of the population) to transition to clean cooking fuels over the period from 2010 to 2050 (Fig. 1b). Although this represents a substantial transition away from solid fuels, 727 million South Asians (35% of the population) may still rely on solid fuels in 2030, leading to between 0.45 and 1.31 million premature deaths per year (Supplementary Table 6).

Global climate policy can achieve notable regional GHG emissions reduction but could also slow the transition to clean cooking fuels. In the C30 and C40 scenarios, South Asian GHG emissions remain within 132% and 148% of 2010 levels by 2050. This is within the range observed from recent global modelling studies, which incorporate and extend into the future India's Cancun pledge of reducing emissions intensity by 20 percent below 2005 by 2020 (ref. 38). If no compensatory access policy measures are put into place, the C30 scenario would increase the perceived average cost to cook with LPG by 28% in 2030 (Supplementary Fig. 8), thereby making LPG unaffordable for 336 million people (16% of the population) who would otherwise have adopted LPG. This could lead to between 173,564 and 351,132 additional premature deaths in 2030 (Supplementary Table 6 and Supplementary Fig. 9). In the C40 scenario, access to clean cooking is further impeded, with an additional 433 million South Asians (21% of the population) unable to afford clean fuels in 2030. Notably, increasing mitigation stringency yields diminishing benefits for climate, but increasing setbacks for clean cooking uptake (see Fig. 1a,b). This begs the question: to what extent can access-support policies shield the poor from the negative effects of stringent climate mitigation? And to what extent can revenues from climate mitigation fund access-support policies?

Cost-effectiveness of access policies

Households can be shielded from high energy prices brought about by climate policies using the same types of instruments that governments would have to put in place to accelerate clean cooking uptake in the first place. Policies that reduce stove costs shift more households to clean fuels per dollar invested than policies to reduce fuel costs (Supplementary Fig. 11). This is because, although stoves represent only a small share of the actual (levelized) cost of cooking with clean fuels, the high upfront costs of clean stoves represent

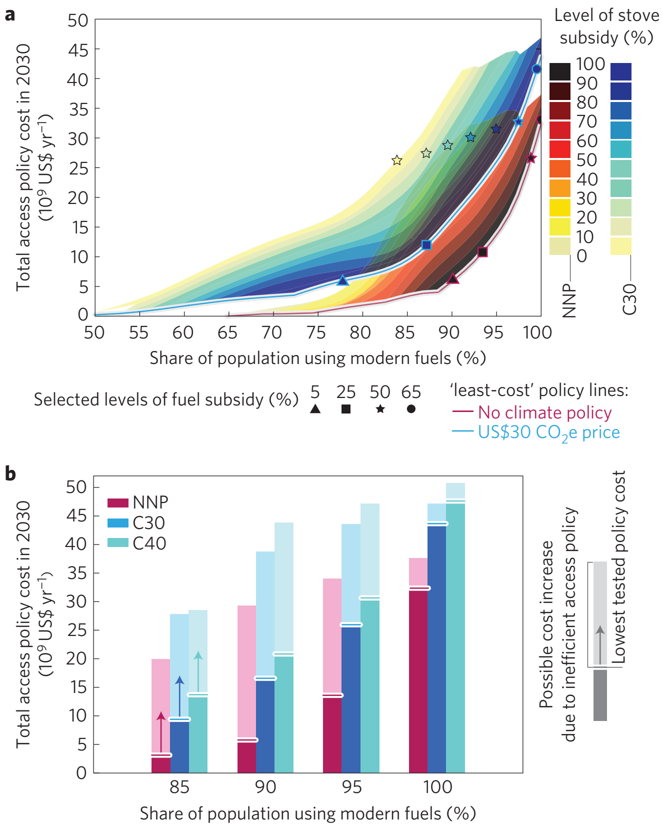

Figure 2 | Access policy cost-effectiveness under baseline and climate mitigation scenarios. a, Fuel and stove price support combinations for the no climate policy (NNP) and US\$30 CO_2e price (C30) scenario in 2030. Colours represent climate policy and stove price support level. Triangles, squares, stars and circles represent 5%, 25%, 50% and 65% fuel price support levels, respectively. An additional representation of fuel price support level can be viewed in Supplementary Fig. 11. 'Least-cost' policy lines are highlighted at the lower end of each of the areas by the cyan and magenta lines. **b**, Total access policy costs in 2030 for the achievement of an 85, 90, 95 and 100% share of population having access to modern fuels, respectively. Dark shaded bars show the lowest policy costs for the respective level of modern fuel access (corresponding to the level indicated by the 'least-cost' policy lines in **a**). Lighter shaded areas show the possible cost increase due to an inefficient access policy (illustrated by the arrows). Results are shown for the NNP, C30 and C40 scenarios.

a larger barrier to clean cooking uptake than fuel prices for many poor households.

The most cost-effective policies are, thus, those with a high stove subsidy (see Fig. 2a, lowest boundary of the shaded areas). Different levels of fuel support yield different levels of access uptake. To achieve a given level of access, the minimum required level of fuel price support increases under climate policy. With NNP, a 5% fuel price support is needed in combination with 100% stove rebate to enable 90% access, but in the C30 scenario, fuel price support must be increased to 25% to achieve the same level of access. To achieve universal access, fuel price support would have to increase to 55 and 65%, respectively, with and without climate policy (at C30).

Our analysis reveals that the choice of access policy instrument has a significant impact on the total cost of expanding clean cooking uptake (Fig. 2a). For example, to achieve 90% clean cooking uptake by 2030 in the absence of climate policy, annual access policy costs can range from US\$6.3 billion to US\$30 billion (Fig. 2b). Achieving universal access will require disproportionately higher costs to make clean cooking affordable to the poorest, ranging from US\$29 billion to US\$38 billion (the range reduces because the stringent goal does not permit much flexibility in instrument design). If ICS technology develops sufficiently to provide health benefits, the poorest 10% of the population in 2030, who would otherwise not afford them, could be provided ICS for an additional US\$8.4 billion. With climate policy (for example, C30), the lowest policy costs to achieve 90–100% access increases to US\$17.1 billion and US\$42 billion, respectively. The C40 scenario could require 44% higher policy costs relative to the NNP scenario to achieve universal clean cooking by 2030.

In comparison, current budget estimates from the Government of India earmark only US\$3.5 billion for LPG subsidies for its new Direct Benefit Transfer (DBT) scheme for households in 2015–16 (ref. 39). By our estimates, this level of annual fuel subsidy will enable only 77% of the population to achieve clean cooking by 2030, assuming no new climate policy. Achieving a 90% clean cooking access goal by 2030 would require reallocating these resources towards stove subsidy and increasing the budget by 80%, or to an estimated US\$6.3 billion per year. Thus, a significant upscaling of access policy costs will be necessary even in a world without climate policies to achieve a 2030 goal.

An equity-based international climate policy regime could provide a potential means to bridge the access finance gap to achieve universal clean cooking by 2030, even under stringent mitigation. That is, if an international climate policy regime adopts a target equivalent to our C30 scenario, and differentiates mitigation efforts among countries based on per-capita emissions, South Asian countries may be a net recipient of monetary flows ranging from −US\$34 billion to +US\$166 billion (with a median of US\$71 billion) in 2030 (ref. 40), which exceeds considerably the US\$42 billion of access policy costs required in the C30 scenario.

Distributional impacts

The impacts of climate and access policies on the population reliant on solid fuels vary significantly among population subgroups. The poorest and richest households (R1 and U2) are least impacted in terms of the percentage of the population affected, whereas the urban poor and higher expenditure rural households (U1 and R2) are likely to be the most affected by climate policy (Fig. 3a), but are also likely to be the most responsive to access policies (Fig. 3b).

R1 cannot afford to cook with clean fuels even in the absence of climate policy (NNP), so mitigation efforts have little impact on the number of solid-fuel users in this group. This group requires substantial fuel and stove support policies to reach even 50% clean cooking access in 2030, even in the NNP scenario. U2 are least affected by climate policy, as they can afford to meet all cooking energy needs with clean fuels starting in 2020 in the NNP scenario and only 10% become unable to afford these in 2050 even in the C30 scenario. They therefore require no policy support in the NNP scenario and only moderate access policy (50% stove support) even under more stringent climate mitigation (C30) to achieve 100% clean cooking in 2030.

R2 are most sensitive to the stringency of climate policies. In the NNP scenario, rising incomes enable R2 to achieve universal access by 2050 (from 3% in 2010). However, in the C10 scenario, an additional 81 million people (68% of the R2 population in 2030) cannot afford clean fuels. In the C30 scenario, over 180 million additional people in R2 do not switch to clean fuels. Although policies to reduce stove cost alone would be sufficient to enable all of R2 to use clean fuels in 2030 in the NNP, additional fuel price support is needed to achieve the same level of energy access for this group in the C30 scenario.

U1 households are frequently unable to collect solid fuels from their environment, and instead purchase wood or subsidized kerosene, depending on their prices[41]. In the NNP scenario, the share of population reliant on solid fuels in U1 drops from 44% in 2010 to 39% in 2030 from rising income. Under carbon mitigation,

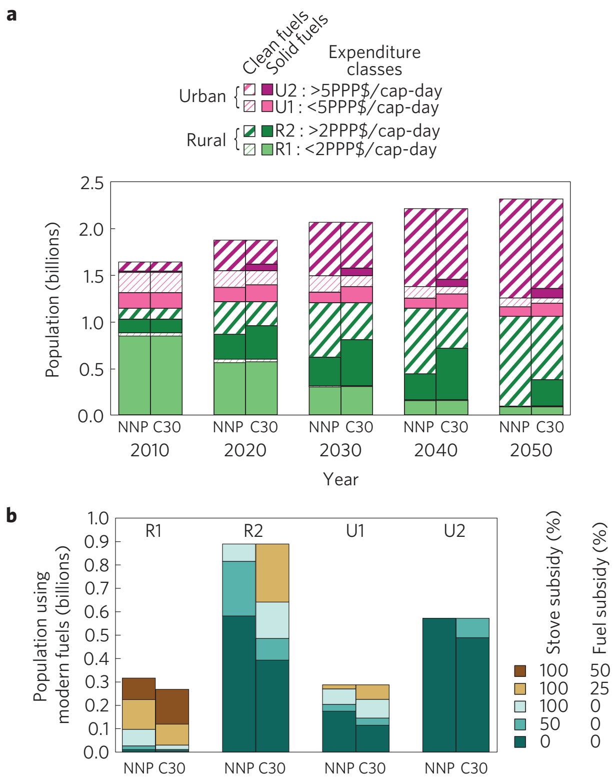

Figure 3 | Distributional impacts of policy. a, Solid and clean cooking in four population groups over time for the NNP and C30 scenarios in the absence of dedicated energy access policies such as fuel price or stove cost support. Population groups are divided according to rural and urban dwelling location and daily per-capita expenditure (under and over PPP$2 per person per day for rural groups and PPP$5 per person per day for urban groups). PPP, purchasing power parity. **b**, Impacts of selected stove cost and fuel price support polices on four expenditure groups in 2030 in the NNP and C30 scenarios.

however, kerosene and LPG prices exceed the cost of purchased biomass. In 2030, therefore, 24% more U1 households rely on solid fuels. Similar to R2, U1 households need only stove support to afford 100% clean cooking in 2030 in the NNP scenario, but require additional fuel support to compensate for higher fuel prices under climate mitigation.

Discussion and policy implications

Our analysis provides insights on how compensatory energy access policies could counteract the effects of climate policies on cooking fuel prices in South Asia. Even in the absence of climate policy, we find that significant upscaling of the intervention policies in place today will be needed to achieve the universal clean cooking target by 2030. Climate mitigation policy could intensify this need, but the ultimate cost of improving access varies more with the choice of access policy mechanism than with the stringency of the climate policy. This result does not justify delay in climate mitigation, but rather stresses the need to account for development objectives in the design of climate policy, such as by designing access policies that efficiently shield poor households from the burden of carbon taxation. Such support policies are further justified given that switching from solid to modern cooking fuels would probably have a negligible impact on climate, as shown by recent studies that account for short-lived climate forcers and unsustainable biomass harvests[21,42,43]. This would bring diverse benefits for the health of economies and people.

We find that a well-designed climate policy could even help mobilize additional resources to bridge the access finance gap. Policy costs for achieving a universal clean cooking goal by 2030 even under stringent climate mitigation could be well within the range of financial transfers that may result from effort-sharing international climate regimes. Clean cooking, given its clear development benefits, may be a good policy option to direct financial transfers that may result from efforts-sharing international climate regimes.

There are some caveats to our analysis. Although we account for fuel price-induced macroeconomic feedback effects, our model does not capture other general equilibrium feedbacks via labour or productivity changes, or the effect of non-ideal institutions. In reality, policy costs may be higher owing to wasted investment or leakage of fuel price support to other economic sectors. On the other hand, policy makers may also have a number of tools at their disposal to reduce access policy costs relative to those estimated here. For example, using microfinance instead of subsidies, or targeting access policies to vulnerable population groups could increase policy efficiency. By systematically modelling a range of access policy mechanisms across increasingly stringent climate mitigation scenarios, our analysis differentiates the impacts of climate and access policies across multiple population subgroups, and offers insights into achieving an ambitious clean cooking target with stringent climate mitigation.

Methods

Fuel-choice model. This study uses a household fuel-choice model, Access, in combination with the global MESSAGE Integrated Assessment energy-economy model, for the years 2005–2100 (see Supplementary Methods for a complete description of methods, data sources, and input assumptions). South Asia is modelled as one of 11 regions in MESSAGE[20,21,25,29]. These two models are run iteratively until convergence: the Access model takes fuel prices from MESSAGE, selects optimal fuel choices for all household groups, and returns aggregate residential demand for the five cooking fuels (LPG, piped gas, electricity, kerosene, and biomass). MESSAGE, in turn, determines the least-cost energy supply pathway to meet these demands and returns new prices. Climate policy is implemented from 2020 through 2100, with the implied carbon equivalent value rising at a discount rate of 5% per year over the time period (see Supplementary Methods).

Access model demographics. The Access model splits the South Asian population into four demographic groups, separated by rural/urban location and daily per-capita expenditure. Expenditure divisions are defined in 2005 purchasing power parity dollar of less than and greater than 2 per day and 5 per day in rural and urban areas, respectively. Average household fuel preferences are determined for each expenditure group for a base year of 2005 using India's National Sample Survey Organization Household Consumer Expenditure Survey[28]. Population, expenditure, and electricity access levels are estimated for each group in future periods based on down-scaled projections of future GDP and population by rural and urban South Asian sub-populations from the GEA-M scenario[26].

Modelling fuel-stove choice. We represent eight fuel-stove options to meet household cooking energy demand: liquefied petroleum gas (LPG), piped gas, electric induction, kerosene, traditional biomass stoves, and improved biomass stoves (ICS) with either natural or forced draft. Fuel-stove options are grouped into three 'fuel tiers', with clean and easy-to-use fuels in Tier 1 (LPG, piped gas, and electricity), intermediate fuels in Tier 2 (kerosene), and dirtier or more time-consuming fuels in Tier 3 (solid fuels). We assume that consumers require a fixed amount of useful energy for cooking, independent of price, but dependent on their expenditure. We estimate demand curves for each fuel for each household group based on survey data, which encapsulates household preferences for that fuel. Given a set of fuel prices, households meet their useful energy demand in order (by Tier) and in proportion to the demand implied by the respective demand curves. In this way, we also account for the multiple fuel use that is the norm in many developing country households (see Supplementary Fig. 10). The preference for higher Tier fuel-stove options for the primary fuel is in line with the evidence from the surveys and the observed energy ladder hypothesis[3]. Owing to the very small number of reported electricity and piped gas users in the household survey, and the relative comparability in terms of the convenience of using electric and gas stoves, we use the LPG demand curve for all three Tier 1 fuel-stove options. Households choose the least-cost Tier 1 option in each period. Stove costs are annualized using household discount rates calculated as a function of expenditure (see Supplementary Methods).

In rural areas, traditional biomass (Tier 3) is the fuel of last resort. Rural households are assumed to have the ability to collect biomass free of cost, making traditional stoves the cheapest option. In urban areas, we assume households are unable to collect biomass, meaning kerosene and purchased biomass fuel-stove options compete on cost. R2 and U2 groups' average energy demand and demand curves are adjusted over time as a function of expenditure and household size using regressions based on household survey data.

Policy scenarios. Price support policies were implemented as percentage reductions on fuel and stove prices in each period. Comparative risk assessment methods consistent with those used by the Global Burden of Disease were used to estimate the health impacts of solid-fuel use (see Supplementary Methods)[44]. Global mean temperature outcomes were computed with the reduced complexity carbon cycle and climate model MAGICC[32] in a probabilistic set-up[33,34], which is consistent with the climate sensitivity assessment of the IPCC's Fifth Assessment Report[35].

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Author contributions

C.C., S.P., N.D.R. and K.R. formulated the research question and conceived the model concept. C.C. implemented the concept by programming and developing the Access model. C.C. and D.M. integrated the Access model into the existing MESSAGE modelling framework. C.C. ran the scenarios. J.R. contributed post-processing analytical tools and input on interpretation of the results, as well as the figures. C.C., S.P. and N.D.R. drafted the manuscript. All authors contributed to editing and discussing the paper.

Additional information

Supplementary information is available online. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to S.P.

Competing interests

The authors declare no competing financial interests.