WPS8008

Policy Research Working Paper 8008

Challenges in Assessing the Costs of Household Cooking Energy in Lower-Income Countries

Michael Toman
Randall Bluffstone

World Bank Group
Development Research Group
Environment and Energy Team
March 2017

Policy Research Working Paper 8008

Abstract

The paper discusses challenges in analyzing the costs of household cooking methods (fuels and associated stove technologies) in lower-income countries, and sources of divergence between observed and true social costs. The challenges in assessing social costs include valuation of household time, impacts of credit constraints on stove selection, preferences for stove characteristics, and the magnitude of health and environmental externalities. All these influences on cost require consideration of the local context.

This paper is a product of the Environment and Energy Team, Development Research Group. It is part of a larger effort by the World Bank to provide open access to its research and make a contribution to development policy discussions around the world. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at mtoman@worldbank.org.

Challenges in Assessing the Costs of Household Cooking Energy in Lower-Income Countries

Michael Toman (Development Research Group, World Bank)

Randall Bluffstone (Portland State University)

Key Words: Household energy. Clean cooking. Improved cookstoves. Energy access. Environment and development. Greenhouse gas emissions.

JEL Classification: Q42, Q53, Q54, Q56, O13

The authors are very grateful to Richard Hosier and Venkata Ramana Putti for comments on earlier drafts of this paper. Financial support for the research was provided by the World Bank Energy Sector Management Assistance Program (ESMAP). Responsibility for the contents of the paper is the authors' alone.

Challenges in Assessing the Costs of Household Cooking Energy in Lower-Income Countries

1. Introduction

Access to modern forms of energy like electricity and natural gas is particularly limited in low income developing countries (UNDP and WHO, 2009), and about two-fifths of the human population still relies on solid cooking fuels combusted in their homes (Grieshop et al., 2011; IEA, 2012; Jeuland and Pattanayak, 2012; Jeuland et al., 2015).[1] Improving access to affordable, reliable and safe forms of modern energy services has become a priority in efforts to reduce poverty and promote economic progress (UNDP, 2005; WHO, 2006; UNDP and WHO, 2009; UNIDO, 2009; AGECC, 2010; World Bank and GACC, 2015). To that end, the United Nations Sustainable Development Goals (SDGs) include three energy targets, to be met by 2030: (1) ensure universal access to affordable, reliable and modern energy services, (2) increase substantially the share of renewable energy in the global energy mix, and (3) double the global rate of improvement in energy efficiency (see https://sustainabledevelopment.un.org/sdg7). The Sustainable Energy for All (SE4ALL) initiative (www.se4all.org) is promoting diffusion of modern energy services in developing countries to meet these goals.

There are several widely recognized reasons for reducing dependence on solid cooking fuels like fuelwood and increasing access to cleaner and improved cooking fuels and technologies. They include greater household convenience; reduced exposure to severe health threats from indoor air pollution; reduced greenhouse gases from lower emissions of black carbon; and the potential for reduced pressures on standing forests, including lower net releases of carbon dioxide from forest degradation.

Against these benefits, however, are considerations related to the cost of providing cleaner and improved cooking energy and devices. Malla and Timilsina (2014) survey the determinants of demands for different cooking fuels and associated cooking technologies, including fuel and cookstove costs. Energy sources such as liquefied petroleum gas (LPG), natural gas and grid-supplied electricity require major public infrastructure investments or costly supply chain development, and often more expensive stoves.[2] A study by IIASA's Global Energy Assessment estimated that for universal access to modern energy by 2030, including electricity grid connections and improved access to clean cooking fuels, $US30 billion to US$41 billion would need to be invested annually (GEA, 2012). While technologies are improving, without (and maybe even with) expanded policies for increasing use of modern cooking energy, the use of traditional biomass fuels by many people will continue for many years (IEA, 2006; 2014).

One key aspect of moving more rapidly away from traditional cooking methods is effectively "pricing in" all the benefits and costs of cleaner and improved cooking. Inclusive measures of the social costs of alternative stove-and-fuel combinations for household cooking, capturing both costs

[1] As of 2016/2017, the World Bank classifies low-income economies as those with a gross national income (GNI) per capita, calculated using the Atlas method, of $1,025 or less in 2015; lower middle-income economies are those with a GNI per capita between $1,026 and $4,035; upper middle-income economies are those with a GNI per capita between $4,036 and $12,475; high-income economies are those with a GNI per capita of $12,476 or more..

[2] Cooking with off-grid electricity is in principle possible, but devices for doing so (including storing sufficient electricity to provide the heat required) are not yet practical.

borne by the household and external effects, provide a conceptually solid base for comparing different options – options that have lower social cost for providing a given level of cooking services would be preferable to options with higher social cost. However, estimating a number of key influences on the costs of alternative cooking modes remains a significant practical challenge.

The paper discusses challenges in analyzing the social costs of household cooking methods (fuels and associated stove technologies) in lower-income countries. These challenges include valuation of household time, impacts of credit constraints on stove selection, preferences for stove characteristics, and the magnitude of health and environmental externalities. All of these influences on cost require consideration of local context.

Section 2 of the paper provides a categorization of fuel-technology options for household cooking. Section 3 provides a general framework for assessing the social cost of different cooking options. Section 4 discusses challenges in assessing social costs. Section 5 shows the wide potential ranges for social costs, depending on particular contexts. . Section 6 contains concluding remarks. The Appendix provides examples of social cost calculation in specific contexts.

2. Characterizing Fuel-Technology Combinations for Household Cooking[3]

Different terminologies and definitions are used in categorizing household cooking energy types (Figure 1).[4] Different types of cookstoves are used by households and these stoves are associated with the availability of specific energy types. Biomass is used in rural areas for traditional cooking (with a pot supported on 3 stones over the fire), and with some simple enclosed stove designs. Kerosene is used for cooking as well as lighting in some areas, especially where it is subsidized. In contrast, cooking stoves using LPG, natural gas and electricity are more common in urban areas, though their direct costs in terms of stove and fuel are higher. In recent years, biogas cookstoves are also gaining popularity in rural areas of some developing countries, though the economics of biogas cooking depends on the availability of cattle dung and the capital cost of the manure digester. There are also efforts to expand the use of bio-ethanol for cooking.

The conversion efficiency of household cookstoves varies widely by stove design and energy sources, and it depends on a variety of site-specific circumstances in developing countries. More modern fuels have high energy content per kg of fuel used, while traditional biomass fuels have low energy content. Traditional fuels also can be much more polluting than modern energy sources, though this depends very much on the type of stove used as well. It is thus important to understand how and why these different types of energy sources and stoves are used for cooking in different parts of the developing world.

[3] This section draws from Malla and Timilsina (2014). See also World Bank and GACC (2015).

[4] In the literature, "fuels" and "energy" are often used interchangeably. In this paper, fuel refers to any material which is used to produce heat or power by burning, and energy refers to heat and power.

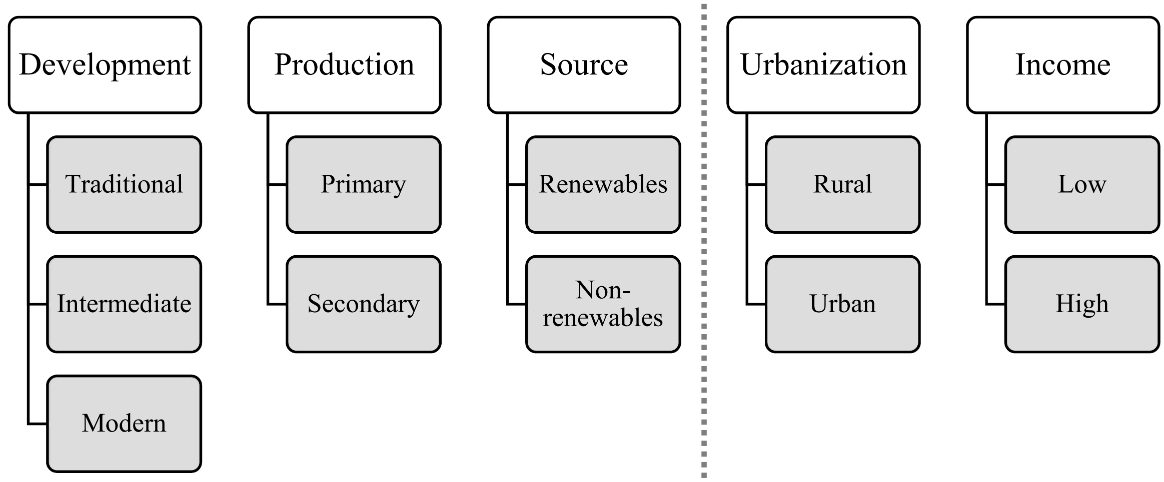

Figure 1. Schematic illustration of categorizing household cooking energy types.

Sources: UN (1982; 2016); IEA (2005, 2012).

3. Defining the Social Costs of Cooking Energy Alternatives

We adopt a holistic definition of the full social costs of cooking energy options that includes, first, the "direct costs," such as investment in stoves and fuel storage (e.g. LPG cylinders), as well as the cost of commercially purchased fuels and the opportunity cost of self-collected fuels (e.g. time spent that could have been spent on some other valuable activities). The full social cost of cooking energy options also includes any non-internalized externalities, such as effects on human health from indoor smoke exposure, forest degradation, and the impacts of greenhouse gas emissions.

To develop a general expression for the social cost of different cooking options, we index different combinations of fuels and stoves by subscripts $i = 0, 1, 2, \ldots$. The index $i = 0$ can be thought of as the most basic technology (e.g., three-stone cooking tripod), with other index values reflecting different improved stove designs and/or alternative fuel types. We would like social cost measures for a comparable amount of cooking activity. To that end, we focus here on cost calculations per annum.

We can write the total annual social cost of using energy-plus-technology type i, denoted SOC_i, as shown in equation (1):

(1) $SOC_i = f_i Q_{im} + FT_i w + k_i + m_i + CT_i w + D_i + \sum_j (d_{ij} + p_{ij} h_j).$

In this equation, k_i is the amortized annual capital cost for the stove, if any,[5] and m_i is the annual stove maintenance cost (if any). f_i is the price per unit of purchased fuel, and Q_{im} is the amount of purchased fuel. For LPG and electricity, f_i should represent the levelized cost including amortized expenditure for associated equipment (LPG canisters, household electricity connection). For biomass fuel that is self-supplied, FT_i is the collection time per annum, while w is a measure of

[5] If the initial capital cost of a stove is K_i, its anticipated life is T_i years, and the annual discount rate is r, then k_i is given by $\sum_{t=0}^{T} \frac{k}{(1+i)^t} = K \leftrightarrow k = K \sum_{t=0}^{T} \frac{1}{(1+i)^t}$.

the unit opportunity cost of time (discussed further below). Because the amount of time spent cooking may differ across technologies, with fast-cooking fuel-technology packages offering time savings benefits compared with other cooking methods, we denote the opportunity cost of cooking time as $CT_i w$, where CT_i is the amount of cooking time. In addition, some stoves may cause more disamenities than others, with amount of household smoke being a primary example. That cost is denoted by D_i. Finally, we denote by d_{ij} the annual value of natural resource damages of type j (e.g., deforestation) from the use of stove-and-fuel combination i; p_{ij} is the annual emission of pollutant type j from stove-and-fuel combination i; and the unit health damage cost of pollutant j is h_j. Then the total opportunity cost of natural resource and health damages for combination i is given by $\sum_j (d_{ij} + p_{ij} h_j)$.

One way to apply (1) to different stove-fuel combinations, given a comparable level of cooking activity, is through controlled cooking tests, in which fuel consumption, cooking time, and (to the extent possible) air quality in the vicinity of the cooking location are measured while cooking the same meals with different methods. Satisfaction surveys can be used in connection with the controlled cooking tests to gauge advantages and disamenities (Beyene et al., 2015), and natural resource damage estimates can be made. This is obviously a time consuming and expensive approach. A simpler but less precise method is to apply (1) to different cooking methods, holding constant the total cooking heat produced as a way of approximating comparable levels of cooking activity.[6] Information about fuel costs and fuel gathering and cooking times also can be collected. This can provide information about the more direct costs borne by the household, but it will not shed light on natural resource damages, health effects, or amenity and disamenity values.

4. Challenges in Assessing Social Costs

The most fundamental challenge in estimating the social cost of cooking technology and fuel combinations is that even direct cost information is often not easily available. Locally relevant information is needed for commercial fuel prices, time spent collecting fuel, and actual costs of stoves in the market. Information on stove performance is also needed, but this can be difficult given the lack of internationally recognized performance standards and testing.

Missing markets for accessing financing can increase the cost for improved stove acquisition or a switch to modern fuels by raising the effective cost of borrowing (Binswanger and Sillers 1983; Yesuf and Bluffstone, 2009). Low-income households may need to make significant investments to take advantage of electricity or LPG availability, and large investments are often needed to establish biogas plants. However, the problem can arise even with much less costly technologies. Bensch et al. (2015) investigate low uptake of improved biomass cookstoves in Burkina Faso and find that the main barrier is affordability – even though the stove model investigated costs between

[6] For $i \geq 1$, let Q_i be total fuel use (purchased and/or collected), HC_i is the heat content of the relevant fuel (joules/kg), and SE_i is a dimensionless number reflecting the stove's conversion efficiency (joules of cooking heat output per joule of energy input). Given the definitions of Q, HC, and SE, we can write total cooking heat output as $H = Q * HC * SE$. Setting $H_i = H_0$ yields $Q_i = \frac{Q_0 HC_0 SE_0}{HC_i SE_i}$. One difficulty with this approach is that it does not allow for what is typically referred to as "rebound effects," in which households enjoy part of fuel savings in the form of additional cooking. Relatively little seems to be known about the size of such cooking rebound effects in lower income settings.

$4.00 and $7.00. Experiments have demonstrated increased interest in acquiring improved biomass cookstoves with availability of micro-finance (Beltramo et al., 2015).

Difficulties in accessing cash employment opportunities can also inhibit investments in modern technologies. Labor markets offer a backstop income source if something goes wrong with agricultural production. If such opportunities are restricted – for example, because of high mobility costs – households may be less willing to take risks.[7] Conversely, improved circumstances for women and girls can increase the opportunity cost of their labor for fuel gathering, affecting the attractiveness of commercial fuels.

A major estimation challenge is how to value household time and other resources used to self-supply and consume energy resources during the cooking process, versus undertaking other productive activities or enjoying leisure. Assessing the opportunity cost requires inferences on alternative uses of inputs devoted to energy self-provision (time, and land if an energy crop is cultivated), and time spent cooking (since different stoves and fuels have different thermal efficiencies and cooking speeds. A measure of local wages is often used to approximate the opportunity cost of time, but this is only true if labor markets and household labor allocations work well. In rural areas of many developing countries labor markets are very thin, implying that households may not be able to get wage employment if they have free time. In such situations, observed market wage rates may be poor proxies for the shadow value of time (Bluffstone, 1995).

Environmental and health impacts are important influences on the social cost of cooking energy that are not reflected in market prices, and may therefore only be partly incorporated into household cooking energy decisions. Prominent among these are the adverse effects on human health of household exposure to smoke, primarily from traditional biomass fuels (Martin et al., 2011; Smith et al., 2013; Lim et al., 2013; Jeuland et al., 2015). Household smoke from biomass burning contains a number of harmful substances (Smith et al., 2013). Exposure to fine particulate matter leads to health damages including acute respiratory infections and chronic pulmonary obstruction, especially for more heavily exposed women and girls. In turn this results in more than 4 million cases of premature mortality, the single largest risk for premature mortality in the developing world (WHO 2014a).[8] A number of other health threats from smoke exposure have been identified, including increased risk of low neonatal birth weight and impeded child cognitive development (World Bank and GACC, 2015).

Reductions in these are therefore important potential benefits from improved stoves and cleaner fuels (Jeuland et al., 2015). However, calculating these economic benefits requires a number of measurements or assumptions about the extent of indoor air quality degradation attributable to household cooking (compared to spillovers from neighbors' cooking or ambient pollution more generally).[9] Information also is needed about the cost of illness from smoke exposure, and the

[7] Difficulties in being able to insure against agricultural and other risks may also affect energy choices. Without insurance, even an occasionally unreliable energy supply chain may be a deterrent to switching to more modern energy. The same would apply when petroleum or natural gas based energy sources exhibit price volatility.

[8] The second largest is exposure to high levels of ambient air pollution, in particular in highly polluted large cities.

[9] Lacey et al. (2017) present remote-sensing based methods for assessing ambient concentrations of both fine particulates and black carbon, notwithstanding the large spatial heterogeneity of these substances.

welfare cost of elevated premature mortality risk (Narain and Sall, 2016), as well as the welfare cost of threats to child health and development.

An additional important question, with philosophical as well as methodological dimensions, involves the extent to which threats to family health are internalized by those making choices about cooking approaches (including fuel, stove type, ventilation, and presence of children), and the extent to which those preferences should drive policy decisions. Rational choice theory would imply that users would balance costs and other factors against health threats when deciding how to cook. In practice, however, households may not be very well informed about the consequences of these choices; may discount the consequences of pollutant exposure, either because of their longer-term nature or for other reasons; may find cleaner stoves or alternative fuels less convenient to use; or for other reasons may value smoke reductions differently – and typically less – than estimates based on highly controlled cost-of-illness studies (Mobarak et al., 2012).

Consequently, greater awareness of the adverse effects of exposure to indoor air pollution may make cleaner fuels or stoves more attractive, but so would offering a package of measures for promoting cleaner and improved cooking alternatives, including greater stove durability and ease of use as well as financing options (Pattanayak et al., 2016). Aside from time discounting, individuals may associate a relatively lower cost with pollutant exposure than would be implied by cost-of-illness studies because they underestimate their own vulnerability, or because long-established habits are not easily changed. Sunstein (2012-2013) provides a discussion of these and other possibilities, and advances the argument that public policy should contain an element of paternalism in such situations by not being entirely bound by revealed individual preferences if those preferences reflect incomplete or incorrect information.

Other health threats for women and girls include insects and snake bites and musculoskeletal injuries associated with collection of fuelwood for cooking. Especially disturbing is that fuelwood collection is one of the key sources of physical and psychological violence against women. Somali refugee women have been raped while gathering fuelwood around camps bordering the Somali-Kenyan border, and women in Sarajevo, Bosnia, faced sniper fire while gathering fuel (Reddy et al. 1997). In Darfur, Sudan, women were frequently assaulted and attacked while collecting fuelwood; many trekked hours at dusk and dawn to avoid exposure to the sun, but these were also the times when walking alone was least safe (Gaye 2008). Fuelwood collection is one of the greatest risks of sexual violence against women in refugee camps in Africa.[10]

Another source of external cost is the contribution of cooking energy use to the accumulation of greenhouse gases in the atmosphere. This could result from net forest degradation from fuelwood gathering (van der Werf et al., 2009; Saatchi et al., 2011), or the effects of "black carbon" – a short-lived pollutant from fuelwood use that contributes to climate change (Bond et al., 2013). Forest degradation can also generate local natural resource damages, such as soil erosion that compromises water sources, and losses of habitats and can increase fuelwood collection times (Cooke et al., 2008; Amacher et al., 2004; Bluffstone, 1995). If forest resources are open access, meaning that collections are uncontrolled, spillover effects of fuelwood harvest decisions on other collectors are likely to not be properly internalized.

[10] Energy Matters: Women at Risk, African Clean Energy, http://www.africancleanenergy.com/energymatters-women-at-risk/.

Table 1 summarizes key context features that can vary not only across fuels, but also across locations. The Appendix provides examples of the application of (1) to actual situations.

Table 1 Likely Magnitudes of Effects of Local Context Factors on Costs of Household Fuels

	Contribution to Increased Household Costs		
Fuel	**Under-developed Fuel Markets**	**Financial Market Distortions**	**Indoor Air Pollution**
Fuelwood	Limited	Low	High
Dung/Ag. Residue	Limited	Low	High
Electricity	Government supplied	Low	Low
LPG	May be high due to transport costs	May be high if first cost is important	Low
Kerosene	Generally limited	Limited	Limited
Biogas	Nontradable. No markets.	Very important, because of high first cost and need for large animals	Low
Fuel	**Poorly functioning labor markets**	**Stronger Standards for Child Schooling and Higher Status of Women**	**Policies Restricting Open Access to Biomass**
Fuelwood	Limited	High, because reduces "free" household labor/increases opportunity cost of time.	High in short run. Possibly negative in long run due to increased productivity of common lands.
Dung/Ag. Residue	Limited	High, because reduces "free" household labor/increases opportunity cost of time.	Likely high in short run, because reduced open access reduces animal raising subsidies. Possibly negative in long run.
Electricity	Limited, because of subsidies	Limited	None
LPG	High	Limited	None
Kerosene	High	Limited	Not directly relevant
Biogas	May be high depending on subsidies	High, because opportunity cost of time rises and biogas depends on animal dung	Likely high in short run, because reduced open access reduces animal raising subsidies. Possibly negative in long run.

5. Ranges for Social Cost Evaluations

A meta-analysis presented in Jeuland and Pattanayak (2012) provides ranges of possible values for many of the key parameters going into the social cost calculation in (1). Their parameter ranges can be used to demonstrate the wide range of potential social costs for different cooking methods. This in turn emphasizes further the importance of local context.

In Table 2 we present the ranges of values from Jeuland and Pattanayak (2012) for direct cost parameters for traditional and ICS. The parameters in Table 2 include the costs of the stove, fuel and cooking time, but leave out health and environmental effects.

Table 2. Components of Direct Cost of Cooking

		Traditional Wood Stove			ICS Improved Wood Stove		
Cost component	Units	Low	Medium	High	Low	Medium	High
(1) Levelized capital cost	$/yr	0	0	0	3	15	50
(2) Cooking time	hrs/day	2	3	4	1.4	2.9	6.0
(3) Energy content of fuel	MJ/kg	16	16	16	16	16	16
(4) Fuel use rate	kg/hr	0.3	0.6	1			
(5) Stove heat transfer efficiency	(none)	0.07	0.11	0.15	0.13	0.25	0.4
(6) % of fuel purchased		0	0.25	0.5	0	0.25	0.5
(7) Fuel price	$/kg	0.03	0.12	0.2	0.03	0.12	0.2
(8) Time collecting fuel	hrs/day	0.3	1	3	0.3	1	3
(9) Additional time for fuel preparation	hrs/day	0	0	0	0.17	0.33	0.5
(10) Wage (cost of time)	$/hr	0.13	0.2	0.5	0.13	0.2	0.5
(11) Annual fuel use	kg/yr	219	657	1460	117.9	289.1	547.5
(12) Annual fuel cost (purchase, collection, preparation)	$/yr	14.24	74.46	419.75	22.3	87.5	419.8
(13) Total annual cost for stove and fuel	$/yr	14.24	74.46	419.75	25.30	102.51	469.75
(14) Opportunity cost of annual cooking time	$/yr	94.9	219	730	66.4	208.1	1095.0
(15) Total annual "direct" opportunity cost	**$/yr**	**109.14**	**293.46**	**1149.75**	**91.73**	**310.56**	**1564.75**

Source: Calculations based on Jeuland and Pattanayak (2012).

Consider first the traditional wood stove. There is no capital or maintenance cost. Lines 2 and 4 give the amount of time spent cooking each day and the fuel use per hour of cooking. Multiplying these two numbers together and then multiplying by 365, we can compute annual fuel use (line 11). Line 10 gives the implicit or "shadow" cost of time based on a nonagricultural wage. Combining lines 2 and 10 and multiplying by 365, can compute the annual opportunity cost of cooking time ($CT_i w$ in equation (1)).

To compute the cost of acquiring fuel, we first apply the percentage in line 6 to calculate the fuel portion of purchased fuel and then multiply by the price of fuel in line 7. This gives us $f_i Q_{im}$ in equation (1). For fuel that is collected, line 8 provides the time spent in collection activity, while line 10 gives the shadow value of that time. Together these give $FT_i w$ in equation (1). Combining the cost figures for purchased and collected fuelwood and multiplying by 365, we obtain the total annual fuel cost in line 12. Combining lines 12 and 14, we calculate the total direct opportunity cost per year (line 15).

To make the calculations for the ICS, we apply the heat-equivalence method described in footnote 9. Lines 3 and 5 give the energy content and the stove heat transfer efficiency (*HC* and *SE*) of the traditional stove and ICS. Applying this equation along with the total fuel use for the traditional stove in line 10 (the parameter Q_0 in footnote 9), we can calculate the total fuel use per year for the ICS. From there the calculations proceed as described above. Of special note is the importance of the implicit (i.e., "shadow") value of cooking time. Women spend a lot of time on cooking and therefore small changes in daily cooking time, depending on the value used, can have big effects. In some scenarios improved stoves reduce cooking time sufficiently to offset higher levels of other costs.

Table 3 presents levelized direct costs for six different combinations of stoves and fuels, including electric stoves, based on the information in Jeuland and Pattanayak (2012). The columns labeled stove+fuel costs omit the opportunity cost of cooking time, in order to highlight the importance of that component.

Table 3. Comparison of Annual Direct Costs for Different Fuel-and-Stove Combinations

Technology	Stove+Fuel Cost ($/yr)			Total Direct Cost including Cooking Time ($/yr)		
	Low	Mid	High	Low	Mid	High
Traditional wood	14	74	420	109	293	1150
Improved wood	25	103	470	92	311	1565
Traditional charcoal	8	91	451	64	255	1181
Improved charcoal	8	81	303	65	245	1033
Kerosene	15	67	200	63	220	857
Propane	63	123	250	107	269	907
Electricity	108	374	789	142	512	1446

Calculations based on Jeuland and Pattanayak (2012).

As can be seen from Table 3, the ranges of potential direct costs for each technology are quite large. The figures suggest that in general more advanced technologies tend to be less costly, because of improved thermal efficiency and higher energy density, even though capital costs and fuel costs may be higher. Less anticipated perhaps is the very wide range of costs. The figures also emphasize the substantial impact of cooking times on opportunity costs.

Tables 4 and 5 present estimated differences in the cost of acute respiratory illness induced by exposure to household air pollutants. Table 4 shows the relative capabilities to reduce acute respiratory illness of the other technologies in Table 3, compared to traditional wood stoves. To translate these relative risk reductions into economic benefits per household, we need the baseline incidence of acute respiratory illness (number of cases per person per year), to which the percentage reductions in can be applied. In addition, we need figures on cost per illness and family size.

The estimates of avoided costs using this information are presented in Table 5. The figures indicate huge ranges for these avoided costs. This reflects the wide ranges of figures for avoided illness and cost of illness in Table 4. Also of considerable interest is that with the exception of the improved woodstove technology, the differences among the technologies in terms of avoided illness cost per family, per year, are not that large. This is a relevant consideration since gas and electric cooking methods tend to be costlier than ICS using biomass.[11]

Table 4: Parameters for Assessing Relative Impacts of Different Cooking Technologies on Social Cost of Acute Respiratory Disease

	Low	Mid	High
Technology	*Percent reduction acute respiratory relative to traditional wood stove*		
Traditional wood	NA	NA	NA
Improved wood	10	40	70
Traditional charcoal	0	20	40
Improved charcoal	10	40	70
Kerosene	45	60	75
Propane	45	60	75
Electric	45	60	75
Cost of illness ($/case)	2	15	60
Baseline incidence (cases/person-year)	0.1	0.5	1.0
Household size (number)	4	5	6

Source: Jeuland and Pattanayak (2012).

[11] WHO (2014b) expresses significant reservations about kerosene use based on safety considerations, and worrisome health risks from vapor inhalation as well as post-combustion air pollution.

Table 5: Avoided Costs of Acute Respiratory Illness per Year, per Family by Technology

	Low	Mid	High
Technology	*Avoided illness cost per family per year relative to traditional wood stove ($/yr)*		
Traditional wood	NA	NA	NA
Improved wood	0.08	15	252
Traditional charcoal	0	7.5	144
Improved charcoal	0.08	15	252
Kerosene	0.36	22.5	270
Propane	0.36	22.5	270
Electric	0.36	22.5	270

Calculations based on Jeuland and Pattanayak (2012).

6. Concluding Remarks

This paper discusses some of the critical elements associated with assessing preferences for and social opportunity costs of alternative cooking energy and technology choices, and some of the key challenges in making those assessments. A significant number of socioeconomic, demographic, behavioral, social, and cultural factors influence preferences. If not effectively addressed, some of these preference determinants become barriers to cleaner cooking adoption. For example, while the cost of modern cookstoves or energy sources can be a barrier for low-income households, the uptake of less expensive ICS can be low even when heavily subsidized. In these cases, stove designs that are unreliable or inconvenient to use, or do not provide customary food tastes, are more significant considerations.

The opportunity cost of cooking energy use likewise depends on a considerable amount of location- and context-specific data on fuel and stove costs and quality, and the opportunity cost of household time, as well as adjustments for a range of market and policy failures affecting cooking energy incentives and choices. In particular, to assess the value of avoided health damages, information is needed on baseline disease incidence, cost of illness and the value of reduced mortality risk, as well as individual attitudes toward such health risks, while information on ecosystem damages and their economic consequences is needed to assess environmental impacts.

What are some priorities among these topics for attention in further empirical work? In a sensitivity analysis examining the principal influences on costs across fuels and stove technologies, Jeuland and Pattanayak (2012) find that for improved stoves burning wood, the key factors influencing cost are the frequency with which improved stoves are used and the cooking time required for each cooking event. If a stove is used infrequently and as a consequence is not used very efficiently, the opportunity cost will be greater than a traditional wood stove. For improved charcoal stoves, time efficiency also matters, but the main drivers of overall cost are the cost of charcoal and improvement in energy efficiency relative to traditional stoves. One implication of these observations is that better understanding stove adoption and use decisions in the field is important for reducing uncertainty about social costs.

As noted above, more highly improved stove technologies and modern fuels have lower total social costs for some but not all plausible values of key underlying parameters. For LPG in particular, the improvement in energy efficiency relative to the traditional stove is key, but so is the baseline incidence of acute respiratory illness. Much of the potential benefit from LPG comes from reduced health impacts. Consequently, if the incidence of respiratory illness is relatively low in the baseline (e.g. due to high ventilation or cooking outdoors), the health benefits from adopting these costlier technologies will be lower; if households do not put a high value on respiratory health risks, the perceived health benefits will be lower. Finally, as one would expect, the energy efficiency of electric stoves and the cost of electricity are significant factors for that technology.

Since more highly improved stoves and modern fuels are likely to remain costlier than less advanced alternatives in a number of locations for some time to come, one key question for increasing the adoption and use of more modern cooking methods is the size of externality costs and how they might be priced into actual transactions. One way this could be done would be through packaging a stove and/or energy source improvement program to include "carbon finance" – payments by third parties reflecting the avoided greenhouse gas emissions of the program. This is already a possibility under existing climate change mitigation mechanisms, such as REDD+. For example, the firm DelAgua Health has distributed more than 100,000 EcoZoom stoves in Rwanda (http://www.delagua.org/projects/rwanda) and Project Surya (www.projectsurya.org) is an interesting example of a nonprofit project relying on carbon finance.

Nevertheless, possibilities are relatively limited as demonstrated by the current low prices of CO_2 in voluntary markets. Extending the scope for such transactions requires not only solid information on the avoided emissions – including solid information on stove and fuel use patterns, not just stoves distributed in the field – but also the evolution of a mechanism for cross-border financing of greenhouse gas emissions reductions under the 2015 Paris Agreement.

Another mechanism can be domestically provided subsidies for improved stoves and modern fuels that reflect the avoided health costs from less clean cooking methods. Calculating the value of such avoided costs requires information on both new stove and fuel use patterns, and on baseline exposure to local pollutants. Beyond the calculations, however, the approach requires strong political commitment to use the public budget to reduce the burden of disease from traditional cooking.

Appendix: Numerical Illustrations of Social Cost Calculations: Cases from Senegal

Traditional Versus Improved Wood Stoves

Bensch and Peters (2015) present results of a randomized controlled trial field experiment involving a wood-fueled ICS in rural Senegal. In this approach, a random sample of rural households was generated, and then a random subset of those households received an ICS. Data were obtained from controlled cooking trials, measurement of wood use in actual practice (to try to account for actual frequency of use of the ICS), and responses to follow-up questions about respiratory illness and eye problems from exposure to cooking smoke. The baseline was a traditional three-stone stove, though some households in the sample also used a traditional (unimproved) metal stove (and this was accounted for in the statistical analysis).

Key information from the field experiment is summarized in Table 6. The first point to note is the low cost of the ICS, which is roughly 0.01 (1 percent) of the 2012 per-capita income in Senegal (based on 2012 UN statistics for Senegal). Information from USAID (n.d.) indicates that the type of ICS used in the experiment could be expected to have a useful life of at least 2-3 years, and often 5-6 years. This implies a cost per year on the order of only 0.2 percent of annual per-capita income).[12]

The next finding is that while firewood consumption drops considerably with use of the ICS (on the order of 31% below the baseline), fuelwood collection time is very little affected by adoption of the ICS. Bensch and Peters (2015) speculate that this could reflect, among other things, household decisions to carry less wood per collection trip, rather than reducing the total time spent on collection. This point illustrates the importance of trying to obtain field-validated data for evaluation of ICS, as opposed to just relying on the assumption that collection time dropped in proportion to wood use.

Table 6. Findings from a field experiment for introducing ICS in Senegal

Parameter	Traditional wood stove	Wood ICS
Stove purchase cost	0	$8-11
Fuelwood collection time (hours per week)	23	22
Firewood consumption (kg/week)	88	61
Cooking duration (hours per week)	39	30
Percentage of households with occurrence of respiratory disease symptoms*	17.3	9.1

Sources: Bensch and Peters (2015); Tijdens et al (2012); USAID (n.d.)

*Based on self-reported information of symptom occurrence over the past three months for at least one woman in the household involved in cooking. Total number of observations = 227.

The drop in wood use is somewhat below the estimate obtained from controlled cooking tests (around 40%). This may in part reflect a typical difference between controlled and in-the-field behaviors. It could also reflect in part to a “rebound effect:” – with a more fuel-efficient stove in effect lowering the opportunity cost of cooking, households may elect to do more cooking (which could also explain the limited impact of the ICS on collection times). Support for this supposition

[12] This rough calculation does not account for the difference between rural and national average incomes, reflecting higher incomes in urban areas. On the other hand, the cost per household will be smaller than indicated in the text given multiple income earners in the household.

is provided by other information in Bensch and Peters (2015) indicating that the ICS reduced firewood use per dish cooked by around 48%.

Notwithstanding any rebound effect, however, Table 6 indicates that the increased thermal efficiency of the ICS significantly reduced time spent cooking (by almost one-quarter). Information from WageIndicator Foundation (Tijdens et al 2012) suggests that a relevant hourly value for this time (based on wage rates for informal sector work) would be \$0.40 – \$0.80 per hour. This would put the weekly value of time saved from the ICS at \$3.60 – \$7.20 per week, implying a very fast payback on the stove cost in terms of the opportunity cost of time alone.

Finally, Table 6 indicates that households with an ICS in the experiment report a sharp decline in the occurrence of respiratory illness symptoms (a decline of almost half in the frequency of symptom reporting within a household, relative to the baseline). To carry out the calculations for the economic value of health benefits shown in Tables 4-5 of the main text, we would need to have figures on typical household size, baseline occurrence of acute respiratory illness, and cost of an episode of illness.

Ethanol, LPG, and Fuelwood

A study by Practical Action et al. (2014) examines possibilities for improved fuels and/or stoves in several different parts of Senegal. We focus here on the part of the study concerned with the possibility of introducing ethanol fuel and stoves in the Saint-Louis region (chapter 5 of the report). Ethanol is of interest in this area because the country's main sugar producer is located there, and is already producing significant quantities of ethanol for non-fuel markets.

The study focuses on the possibility of ethanol fuel penetration in the *urban cooking energy market* within Saint-Louis, and so we begin with that here. According to figures supplied by Practical Action et al. (2014), the urban population in 2010 was about 394,000, about 44% of the total population. About 60% of the region's urban population already are using LPG. However, many of them also use charcoal as a secondary fuel, and charcoal is used as the primary fuel by the majority of the other households; about 75% of all urban households have a simple charcoal stove, while 16% have an improved charcoal stove.

As noted, the cost comparison between ethanol and LPG for cooking needs to take into account a variety of factors including fuel cost differences and differences in their thermal content, differences in amortized stove cost and thermal efficiency, and differences in environmental impacts. The Practical Action et al. (2014) report indicates that both ethanol and LPG stoves have a conversion efficiency of about 50%. It provides a range for potential ethanol stove costs of \$30-\$60, but does not provide information on LPG stove costs.

To look more deeply into this, we drew upon information in a review of clean cooking alternatives for all of Sub-Saharan Africa (World Bank, 2014). Appendix 1 of that report indicates that more sophistical ethanol stoves would cost on the order of \$50-\$80 (cheaper but less durable stoves using gel alcohol cost less). Multiple burner LPG stoves would cost on the order of \$50-\$90 (less convenient single burner ones, \$10-\$50). Figure 44 in the main body of the report indicates that the LPG stove is typically costlier than an ethanol stove, but only modestly so – and such a cost difference likely would be even smaller in Senegal given an established urban market for LPG.

We can thus conclude on the basis of this information on stove costs and conversion efficiencies that differences in stove costs are more of a second-order consideration in comparing ethanol and LPG. Similarly, Figure 11 of World Bank (2014) suggests that the environmental performances of the two stove-plus-fuel options are likely to be fairly comparable. Accordingly, the main factor to consider initially is how the two fuel costs compare.

Practical Action (2014, Annex A) reports that LPG costs are CFAF 666-814 per kg, depending on cylinder size (the higher unit cost is for the smaller cylinder). Using an exchange rate of CFAF 500 = $US1, we can express this as $1.33-1.63/kg. Given 42.5 MJ of energy per kg of LPG, we can re-express this range as $0.031 - $0.039/MJ.

To compare these figures to the cost of ethanol, we must speculate on the price of fuel-grade ethanol since no market currently exists. It turns out that the sugar producer produces as a joint product with industrial grade (100%) ethanol a supply of 90-95% ethanol (referred to as "head.") This material has no market currently and the company burns it off, although it would be well suited for fuel. The company has indicated that it believes it could supply fuel grade ethanol for a price of CFAF 320 per liter. Since there are 28MJ/liter of ethanol, this indicative price is equivalent to $0.023/MJ.

These figures would seem to indicate that ethanol is less costly. However, the ethanol price used above is a producer price, while the LPG figures are consumer prices including cost of distribution to retail suppliers. The difference shown above may not be enough to make ethanol cost-competitive at delivery.

Yet, this comparison is not the end of the story. At present, the producer of the fuel-grade ethanol burns off the product because it has no market outlet and thus no economic value. If an urban market for ethanol fuel were to develop, a price far lower than CFAF 320 per liter would provide the producer with a more profitable alternative to the status quo.[13] By this reasoning, the development of an urban ethanol fuel market in Saint-Louis (along with a market for the stoves) would seem quite promising; the issue instead is putting in place the supply chains.

Let us turn now to consideration of the potential for *ethanol use in rural Saint-Louis*. This involves comparing ethanol costs versus costs associated with a traditional 3-stone stove that is used by 89% of people in rural Senegal. Practical Action et al (2014) concludes that there is little prospect for penetration of ethanol into rural areas in the nearer term, given differences in fuel and stove costs and set-up costs for supply chains associated with bringing ethanol fuel and stoves to rural areas. In Table 7 we use parameters from Practical Action et al (2014) and other sources to further investigate the comparison.

Practical Action et al. (2014) indicate that in rural Saint-Louis, about 98 kg per household of fuelwood is used each month, with about 25% collected and the remainder purchased. Annex A of their report indicates that the price of fuelwood in Saint-Louis is CFAF 80-100 per kg. Using the approach shown in Table 2, we can compute the monthly cost of fuelwood as follows. The monthly cost of fuelwood purchased, 75% of 98kg or about 74kg, would be CFAF 5880-7350 or $US11.76- 14.70. From the figure of 23 hours per week for fuelwood collection time in Table 6, which assumed no purchases, we could infer that about 23 hours per month would be spent

[13] Presumably the floor price for the producer is above zero because there would be costs of maintaining availability of the "head," in particular costs of storage.

collecting fuelwood in rural Saint-Louis. Valuing that time at an opportunity cost of $0.40-0.80/hr, we find that the total opportunity cost of fuel for the traditional wood stove users per month would be roughly $20.96-33.10.

Table 7. Comparing ethanol and traditional woodstove cooking in rural Saint-Louis region, Senegal

Parameter	Traditional wood stove	Ethanol
Stove purchase cost	0	$50-80[&&]
Fuelwood collection time (for ¼ of total use)	23 hours/month[*]	NA
Opportunity cost of fuelwood collection time (at $0.40-0.80/hr)[**]	$9.20-18.40/month	NA
Total fuel consumption	98 kg/month	0.5 liters/month [#]
Fuel price	$0.16-0.20/kg	$0.64/liter?[##]
Total opportunity cost of fuel[***]	$20.96-33.10 per month	$19.20 per month?
Cooking duration[&]	156 hr/month	109 hr/month
Opportunity cost of cooking time (at $0.40-0.80/hr)[**]	$62.40-$124.80/month	$43.60-87.20/month
Total non-stove costs	$92.56-176.30/month	$62.80-106.40/month

Sources: See notes.

[*]Based on collection time per week in Table 6.

[**]See text for discussion of the range of unit time values.

[***]Equal to the opportunity cost of collection time for one-fourth of total fuelwood use plus total purchase cost for three-fourths of fuelwood use.

[&]Entry for wood stove comes from Table 6. The figure for ethanol assumes that this cooking fuel and technology has about the same cooking time savings relative to a traditional wood stove as a kerosene stove, which in turn are taken from Jeuland and Pattanayak (2012) (the figures behind the summary cost numbers in Table 3).

[&&]Cost range for a more sophisticated stove; could significantly overstate the actual cost of a smaller and less durable stove using alcohol gel.

[#]See text for explanation of this figure.

[##]As noted in text, the actual price of ethanol fuel for consumers in Saint-Louis is uncertain. This figure does not include distribution costs but likely is an upper bound for the cost of fuel at the plant gate.

Practical Action et al. (2014) also indicate that typical use of ethanol for cooking is on the order of 1 liter per day. Given the other information they provide in their Annex A, including 50% average conversion efficiency for ethanol stoves and 28MJ/liter for ethanol fuel, 1 liter/day of fuel use implies 420MJ of useful heat from ethanol for cooking each (30 day) month. In contrast, with an average efficiency of a 3-stove of 12%, 18MJ/kg for fuelwood, and 98kg of fuelwood used per month, total useful heat for cooking with a tradition stove would be about 212MJ. This large disparity in heat use goes against the key assumption of Jeuland and Pattanayak (2012) that heat demand can be treated as constant across stove-plus-fuel options.

One explanation for this could be that the figure of 1 liter per day of ethanol use is for higher-income urban households, since urban ethanol use is the focus of the Practical Action et al analysis. With higher incomes, demands for energy use in cooking also would be larger. We thus *assume* for the purpose of the analysis that follows that if ethanol could penetrate into rural areas, its use would be more like 0.5 liters/day. This makes the two levels of heat consumption referenced above almost identical between the two fuels.

We discussed above that the actual price of ethanol fuel for consumers in Saint-Louis is uncertain. The figure in Table 7, which reflects information in the Practical Action et al. report, does not include distribution costs but likely is an upper bound for the cost of fuel at the plant gate. This of course makes the monthly cost of ethanol fuel uncertain as well.

We noted in connection with Tables 2 and 3 that differences in cooking time can be an important element in comparing opportunity costs of different cooking approaches. In Table 7, the cooking time figure for ethanol assumes that this cooking fuel and technology has about the same cooking time savings relative to a traditional wood stove as a kerosene stove, which we can compute using figures in Jeuland and Pattanayak (2012) that were also used in Table 3. Both cooking durations then can be valued at the same hourly opportunity cost as that applied to wood collection.

Overall, Table 7 suggests that the fuel cost of ethanol might be competitive with fuel costs (purchasing and gathering) for traditional wood stoves, even before considering differences in cooking times – assuming a reasonable well-functioning supply chain can be put in place. Clearly delivery cost for rural markets would be higher than for urban markets. On the other hand, for reasons already discussed, the producer price for ethanol fuel in Saint-Louis could be quite a bit lower than the figure stated in the Practical Action et al. report. If this price, as set in an urban ethanol market in Saint-Louis, were well below the figure in Table 7, there could be "room" for a considerable distribution cost margin.

So far, we have not accounted for the ethanol stove cost. The \$50-\$80 purchase cost translates into \$1.32-\$2.11/month if amortized over 5 years (well under the working stove life) at a borrowing rate of 20%. Thus, while the up-front cost certainly can be a barrier, even relatively costly small-scale financing could make it reasonably affordable (assuming also that repayment can be reasonably assured).

Finally, recall from the discussion above that ethanol stoves could reduce health-damaging emissions from traditional solid fuel combustion by something like 95%. Even if ethanol use in rural areas was not cost-competitive with traditional stoves, there could be a case for subsidizing it as a way of establishing its use in order to address that serious public health issue. More in-depth analysis of the case would be needed to settle this and other issues noted above.

References

AGECC (Advisory Group on Energy and Climate Change). 2010. *Energy for a Sustainable Future*. New York: United Nations. Available at: http://www.unido.org/fileadmin/user_media/Publications/download/AGECCsummaryreport.pdf

Amacher, G., L. Ersado, D.L. Grebner, and Hyde, W. 2004, “Disease, microdams, and natural resources in Tigray, Ethiopia: Impacts on productivity and labour supplies.” *Journal of Development Studies* 40: 122–145.

Bailis, R, R. Drigo, A. Ghilardi, O. Masera. 2015. “The Carbon Footprint of Traditional Woodfuels,” *Nature Climate Change* 5: 266- 272.

Barnes, D. F, S. R. Khandker, and H. A. Samad. 2011. "Energy poverty in rural Bangladesh." *Energy Policy* 39 (2):894-904.

Beltramo, T. and D.I. Levine. 2013. “The Effect of Solar Ovens on Fuel Use, Emissions and Health: Results from a Randomised Controlled Trial.” *Journal of Development Effectiveness* 5: 178–207.

Bensch, G. and J. Peters. 2015. “The Intensive Margin of Technology Adoption – Experimental Evidence on Improved Cooking Stoves in Rural Senegal.” *Journal of Health Economics* 42: 44-63.

Binswanger, H., and D. Sillers. 1983. “Risk Aversion and Credit Constraints in Farmers Decision-Making: A Reinterpretation.” *Journal of Development Studies* 20: 5–21.

Bluffstone, R. 1995, “The Effect of Labor Markets on Deforestation in Developing Countries under Open Access: An Example from Rural Nepal.” *Journal of Environmental Economics and Management* 29: 42–63.

Bond, T., Doherty, S., Fahey, D., Forster, P., Bernsten, T., DeAngelo, B., Flanner, M., Ghan, S., Karcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P., Arofim, M., Schultz, M., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S., Hopke, P., Jacobsen, M., Kaiser, J., Klimont, Z., Lohmann, U., Schwarz, J., Shindell, D., Storelvmo, T., Warren, S. and Zender, C. 2013. “Bounding the role of black carbon in the climate system: A scientific assessment.” *Journal of Geophysical Research Atmospheres* 118: 5380–5552.

Gaye, A. 2008. “Access to Energy and Human Development,” United Nations Development Program Human Development Report Office Occasional Paper. New York: UNDP. Available at: http://hdr.undp.org/sites/default/files/gaye_amie.pdf.

GEA (Global Energy Assessment). 2012. *Global Energy Assessment - Toward a Sustainable Future*. Cambridge University Press, Cambridge, UK and New York, NY, USA and the International Institute for Applied Systems Analysis, Laxenburg, Austria.

Grieshop, A. P., J. D. Marshall, and M. Kandlikar. 2011. "Health and climate benefits of cookstove replacement options." *Energy Policy* 39 (12):7530-7542.

IEA (International Energy Agency). 2005. *Energy Statistics Manual*. Paris: IEA.

IEA (International Energy Agency). 2010. *World Energy Outlook 2010*. Paris: IEA.

IEA (International Energy Agency). 2012. *World Energy Outlook 2012*. Paris: IEA.

IEA (International Energy Agency). 2014. *World Energy Outlook 2014 Factsheet*. Paris: IEA.

Jeuland, M.A. and S.K. Pattanayak. 2012. "Benefits and costs of improved cookstoves: Assessing the implications of variability in health, forest and climate impacts." *Plos ONE* 7(2): 1-15.

Jeuland, M. A, Pattanayak, S. and Bluffstone, R. 2015. "The economics of household indoor air pollution." *Annual Review of Environmental and Resource Economics* 7(1): 81-108.

Lacey, F.G, D. K. Henze, C. J. Lee, A. van Donkelaar, and R. V. Martin, "Transient climate and ambient health impacts due to national solid fuel cookstove emissions." *PNAS* 114(6): 1269–1274.

Lim, S. S., T. Vos, A. D. Flaxman, G. Danaei et al. 2012. "A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010." *The Lancet* 380 (9859): 2224-2260.

Madubansi, M., and C. M. Shackleton. 2007. "Changes in fuelwood use and selection following electrification in the Bushbuckridge lowveld, South Africa." *Journal of Environmental Management* 83 (4):416-426.

Malla, S., and G. R Timilsina. 2014. "Household cooking fuel choice and adoption of improved cookstoves in developing countries : a review." Policy Research Working Paper 6903. Washington, DC, World Bank , June. Available at: http://documents.worldbank.org/curated/en/542071468331032496/Household-cooking-fuel-choice-and-adoption-of-improved-cookstoves-in-developing-countries-a-review.

Martin II, W J., R. I. Glass, J. M. Balbus, and F. S. Collins. 2011. "A major environmental cause of death." *Science* 344: 180-181.

Mobarak, A. M, P. Dwivedi, R. Bailis, L. Hildemann, and G. Miller, 2012. "Low demand for nontraditional cookstove technologies," *Proceedings of the National Academies of Sciences* 109: 10815-10820.

Modi, V., S. McDade, D. Lallement, and L. Saghir. 2005. *Energy Services for the Millennium Development Goals*. Washington, D.C. and New York: World Bank and UNDP.

Narain, U. and C. Sall. 2016. *Methodology for Valuing the Health Impacts of Air Pollution: Discussion of Challenges and Proposed Solutions*. Washington DC: World Bank. Available at: http://documents.worldbank.org/curated/en/832141466999681767/pdf/106607-WP-ADD-AUTHORS-ABSTRACT-PUB-DATE-PUBLIC.pdf

Practical Action Consulting, Enda, and World Bank. 2014. *Baseline and Feasibility Assessment for Alternative Cooking Fuels in Senegal*. Washington, DC, World Bank, May. Available at: https://openknowledge.worldbank.org/bitstream/handle/10986/18956/884510WP0REPLA0g0May20140Box385191B.pdf?sequence=1&isAllowed=y

Reddy, A.K.N., R.H. Williams, T.B. Johansson, S. Baldwin. 1997. *Energy After Rio*. New York: UN Development Programme.

Saatchi SS, Harris NL, Brown S, Lefsky M, Mitchard TAE, Salas W, Zutta BR, Buermann W, Lewis SL, Hagen S, Petrova S, White L, Silman M and Morel A. 2011. "Benchmark map of forest carbon stocks in tropical regions across three continents." *Proceedings of the National Academies of Sciences* 108(24): 9899-9904.

Smith, K. R., H. Frumkin, K. Balakrishnan, C. D. Butler, Z. A. Chafe, I. Fairlie, P. Kinney, T. Kjellstrom, D. L. Mauzerall, T. E. McKone, A. J. McMichael, and M. Schneider. 2013. "Energy and human health." *Annual Review of Public Health* 34:159-188.

Sunstein, C. R. 2012-2013. “The Storrs Lectures: Behavioral economics and paternalism.” *Yale Law Review* 122: 1826-1899.

Tijdens, K, J. Besamusca, A. Kane, and E.N. Tingum. 2012. *Wages in Senegal: WageIndicator Survey 2012.* Amsterdam, WageIndicator Foundation, November. Available at: http://www.wageindicator.org/documents/publicationslist/publications-2012/AIAS_WI_f2f_countryreport_Senegal_20121205_en.pdf

UN 1982. *Concepts and Methods in Energy Statistics with Special Reference to Energy Accounts and Balances.* New York: United Nations. Available at: https://unstats.un.org/unsd/publication/SeriesF/SeriesF_29E.pdf

UN 2016. *International Recommendations for Energy Statistics (IRES).*Department of Economics and Social Affairs, Statistical Papers Series M, Number 93. New York: UN. Available at: https://unstats.un.org/unsd/energy/ires/IRES_Whitecover.pdf

UNDP. 2005. *Energizing the Millennium Development Goals: A Guide to Energy’s Role in Reducing Poverty*. New York: UNDP. Available at: http://www.undp.org/content/undp/en/home/librarypage/environment-energy/sustainable_energy/energizing_the_mdgsaguidetoenergysroleinreducingpoverty.html

UNDP and WHO. 2009. *The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa*. New York: UNDP. Available at:
http://www.undp.org/content/dam/undp/library/Environment%20and%20Energy/Sustainable%20Energy/energy-access-situation-in-developing-countries.pdf

UNIDO. 2009. *Scaling up Renewable Energy in Africa*. 12th Ordinary Session of Heads of State and Governments of the African Union, Addis Ababa, Ethiopia. Vienna: United Nations Industrial Development Organisation (UNIDO). Available at: https://www.unido.org/fileadmin/user_media/Services/Energy_and_Climate_Change/Renewable_Energy/Publications/Scaling%20Up%20web.pdf

USAID (US Agency for International Development). n.d. Senegal Household Energy Project: October 1996 — January 2002. Available at: http://www.enterpriseworks.org/recentprog_energy_sen.asp.

van der Werf, G. R.; D. C. Morton; R. S. DeFries; J. G. J. Olivier; P. S. Kasibhatla; R. B. Jackson; G. J. Collatz; and J. T. Randerson. 2009. “CO_2 Emissions from Forest Loss,” *Nature Geoscience* 2: 737 – 738.

World Health Organisation (WHO). 2006. *Fuel for Life: Household Energy and Health*. Geneva: WHO. Available at: http://www.who.int/indoorair/publications/fuelforlife.pdf

World Health Organisation (WHO). 2014a. *Burden of Disease from Household Air Pollution for 2012: Summary Report*. Geneva: WHO. Available at: http://www.who.int/phe/health_topics/outdoorair/databases/FINAL_HAP_AAP_BoD_24March2014.pdf

WHO (World Health Organization). 2014b. *WHO Indoor Air Quality Guidelines: Household Fuel Combustion*. Geneva, WHO. Available at: http://apps.who.int/iris/bitstream/10665/141496/1/9789241548885_eng.pdf?ua=1

World Bank. 2014. *Clean and Improved Cooking in Sub-Saharan Africa*. Washington, DC: World Bank.

World Bank and Global Alliance for Clean Cookstoves (GACC). 2015. *The State of the Global Clean and Improved Cooking Sector*. ESMAP Technical Report 007-15. Washington, DC: World Bank. Available at: http://documents.worldbank.org/curated/en/385081467992479462/pdf/96499-ESM-P127219-PUBLIC-Box391453B-ESMAP-State-of-Globa-Clean-Improved-Cooking-sector-Optimized.pdf

Yesuf, M. and R. Bluffstone. 2009. "Poverty, Risk Aversion and Path Dependence in Low Income Countries: Experimental Evidence from Ethiopia," *American Journal of Agricultural Economics* 91(4): 1022-10.