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Household air pollution, health, and climate change: cleaning the air

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Jose Goldemberg¹, Javier Martinez-Gomez², Ambuj Sagar³ and Kirk R Smith^{4,5} 

¹ Instituto de Energia e Ambiente da Universidade de São Paulo, São Paulo, CEP 05508-010 Brazil

² Instituto Nacional de Eficiencia Energética y Energías Renovables; Universidad Internacional SEK Ecuador, Quito, EC170134, Ecuador

³ School of Public Policy and Department of Humanities and Social Sciences, Indian Institute of Technology Delhi, New Delhi, 110016, India

⁴ School of Public Health, University of California, Berkeley, CA 94720-7360, United States of America

⁵ Author to whom any correspondence should be addressed.

E-mail: krksmith@berkeley.edu

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Abstract

Air pollution from the use of solid household fuels is now recognized to be a major health risk in developing countries. Accordingly, there has been some shift in development thinking and investment from previous efforts, which has focused only on improving the efficiency of household fuel use, to those that focus on reducing exposure to the air pollution that leads to health impact. Unfortunately, however, this is occurring just as the climate agenda has come to dominate much of the discourse and action on international sustainable development. Thus, instead of optimizing approaches that centrally focus on the large health impact, the household energy agenda has been hampered by the constraints imposed by a narrow definition of sustainability—one primarily driven by the desire to mitigate greenhouse emissions by relying on renewable biomass fueling so-called improved cookstoves. In reality, however, solid biomass is extremely difficult to burn sufficiently cleanly in household stoves to reach health goals. In comparison to the international development community, however, some large countries, notably Brazil historically and more recently, India have substantially expanded the use of liquefied petroleum gas (LPG) in their household energy mix, using their own resources, having a major impact on their national energy picture. The net climate impact of such approaches compared to current biomass stoves is minimal or non-existent, and the social and health benefits are, in contrast, potentially great. LPG can be seen as a transition fuel for clean household energy, with induction stoves powered by renewables as the holy grail (an approach already being adopted by Ecuador as also discussed here). The enormous human and social benefits of clean energy, rather than climate concerns, should dominate the household energy access agenda today.

1. Introduction

Addressing the climate challenge while advancing development needs is at the heart of a conundrum for developing countries and other actors in the climate/development arena. Effective management of this perceived tension is the key to creating political support and engagement on the climate issue in developing countries. The ideal action, of course, is that which provides an opportunity to meet pressing development needs while also resulting in greenhouse gas mitigation. But as is often the case, the reality turns out to be more complicated and the navigation of

the climate/development nexus may lead to outcomes in which developmental aspects are not given sufficient attention in the urgent push to tackle the climate problem. Household air pollution (HAP) from solid cookfuel is a case in point.

2. The HAP problem

The environmental, social and human health consequences of the reliance of a significant part of the developing world on biomass burnt in traditional cookstoves have been well articulated for about four

decades now, although the health component has only relatively recently been fully explored (Lim *et al* 2012, Smith *et al* 2014).

As a result, there have been a number of efforts since the 1980s to promote so-called improved biomass cookstoves (IBCs) in many parts of the world⁶. As understanding of the household cooking energy problem has evolved (from a natural resource conservation problem to an environmental and social problem to a health and climate problem), so have the objectives of programs aimed at improving this area.

In addition to the human and social impact of relying on traditional biomass cook stoves, such as the drudgery and time lost in collecting firewood, the current state of scientific understanding indicates that the health impact resulting from direct exposure to biomass cooksmoke leads to about 2.2–3.6 million excess deaths per year, accounting for about 3.9%–6.4% of global mortality (GBD 2015), making air pollution (household and ambient) the largest environmental source of ill-health globally. The two types of air pollution are linked, however, in that about 500 000 deaths from the total mortality figure due to ambient air pollution are attributable to the global contribution of household fuels (Chafe *et al* 2014, Lelieveld *et al* 2015, Urban Emissions 2017, GBD MAPS Working Group 2018).

The products of the incomplete combustion of biomass in cookstoves has an impact on the climate, both through carbon dioxide (CO₂) and such climate-related gases as methane (CH₄), nitrous oxide (N₂O), carbon monoxide (CO), and non-methane volatile organic contaminants (NMVOCs) as well as black carbon, with the latter receiving substantial attention in recent years, motivated by a desire to enable quick action on climate change through a focus on short-lived climate-forcing (SLCF) agents, especially given the inability of major industrialized economies to take the lead on significantly reducing CO₂, which is the major greenhouse gas. The co-benefits of reducing many SLCFs, such as reducing local air pollution and health impacts, provides an additional impetus for focusing on these greenhouse pollutants (Bruce *et al* 2017).

Accordingly, most major household clean cooking energy programs now cite health as well as climate benefits as the underlying key rationale for these efforts⁷. In addition to the gains from improved stove performance, other developmental objectives such as entrepreneurship and job creation, use of local resources, local and women's empowerment and forest protection also often enter the picture. Here, however, we just focus on health and climate.

⁶ We use 'improved' here in deference to common practice, although believing it to be a poor term—improved in what way and compared to what?

⁷ For example, the 2016 Progress Report of the Global Alliance for Clean Cookstoves is titled 'Clean Cooking: Key to Achieving Global Development and Climate Goals.' (<http://cleancookstoves.org/>).

2.1. Re-examining the 'conventional wisdom'

With all the focus and activities on the area of HAP, two aspects have remained more or less unchanged over the years: the main solution of choice, IBCs, and the number of people continuing to cook with traditional cookstoves—around 2.7 billion (Bonjour *et al* 2013).

IBCs have the advantage of being able to use a locally available, often free, energy source. Furthermore, devices that allow for the better combustion of biomass reduce the resulting pollution of local and non-CO₂ greenhouse gas pollutants. At the same time, since biomass is often thought to be an entirely renewable resource, it often is assumed that the use of IBCs will effectively also lead to net zero CO₂ emissions.

The reality is rather different. IBCs, while less polluting than their traditional three-stone counterparts in laboratory tests, usually do not perform as well in the field (Jetter *et al* 2012, Shen *et al* 2018). This is not surprising since the operating conditions of actual use differ greatly from the laboratory, with far less consistent operator behavior and less consistent use of biomass, including size and moisture content (WHO 2014). Indeed, even the term 'improved' is often rather loosely used in reality, with no uniform performance standards for the dissemination of stoves that may be labeled as cleaner and/or more efficient. Evolving standards/guidelines from the ISO and WHO, however, show promise in helping with this vagueness (WHO 2014, ISO 2012).

The latest understanding of the non-linear nature of air-pollution-exposure-risk relationship also suggests that emissions from cookstoves have to be reduced significantly in order to adequately protect human health (Smith *et al* 2014, Burnett *et al* 2014). Unfortunately, even today's best IBCs are not yet able to reliably deliver this level of performance in the field. Progress is proceeding, however, and perhaps eventually there will be devices that are clean, attractive and reliable to be promoted as health-giving interventions.

We ourselves have proposed a global innovation prize as a way to motivate and bring on board a variety of actors who may have the capabilities to develop a clean-burning, robust and affordable biomass cookstove (Sagar and Smith 2013). But as with any technical change, the rate of progress is uncertain, especially in this case where the clean combustion of solid fuels is naturally constrained by the physics of fuel-air mixing and the high heterogeneity of biomass sources, and an enormous market to drive deep and sustained technical change is lacking.

Experience of scaling up the delivery of IBCs has also been mixed. While a total of a few hundred million improved cookstoves have indeed been disseminated over 35 years in a number of developing countries (including India, Nepal, Kenya, Sri Lanka and Peru), these numbers are dominated by the large program in China that ended in the mid 1990s. That these numbers are far fewer than what is needed is

evinced by the increasing number of people who are continuing to cook with traditional cookstoves outside of China. This is not surprising since establishing production, supply and servicing chains at this scale of delivery would indeed be an enormous task. In addition, it should be noted that the small set of IBCs that seem most capable of reducing exposure require processed biomass briquettes or biofuels such as ethanol, which themselves require a second supply chain. Also, monetizing biomass through this second supply chain may have unintended consequences in terms of local biomass supply and use patterns—induced demand in the commercial sector, for example. Furthermore, many of these IBCs have relatively short lifetimes in actual use and are not replaced by households due to their not being perceived as offering significant benefits and/or meeting their needs (Puzzolo *et al* 2016).

It is also observed, although not as systematically studied, that most of these IBCs do not completely replace traditional stoves, but are rather ‘stacked’ in that they are used along with a certain continuation of traditional devices (Piedrahita *et al* 2011, Lewis and Pattanayak 2012, Rehfuess *et al* 2014, Pillarisetti *et al* 2014). The health benefit, however, depends even more on reducing the use of traditional polluting devices than directly using newer cleaner ones.

As things stand at present, IBC programs have had only limited success in replacing traditional biomass for cooking energy (GACC 2017) and even where they have done so, the lack of sufficient reduction in air pollution exposure in real household IBC use undercuts their promise of major improvements to the health risk, even though such devices do somewhat address the climate issue (WHO 2014).

Given these issues with IBC performance and dissemination, it is perhaps surprising that such cookstoves continue to be the centerpiece of clean household cooking energy. To our mind, the continued impetus on clean cookstove programs, in reality, stems more from climate change concerns expressed as a focus on renewable energy. This is evinced by the rapid rise in funding for programs such as the Global Alliance for Clean Cookstoves (GACC) and Energising Development (EnDev), which is an energy access partnership currently financed by six donor countries. If health is indeed a key element of the focus on clean cooking energy, it is difficult to justify the continuing emphasis of using such devices, rather than other demonstrated clean fuel solutions.

Notably, ‘market-based’ approaches in major clean cooking energy programs dominate. EnDev facilitates the dissemination of these stoves through self-sustaining markets. GACC and the World Bank support market-based approaches that bring together the assets of the public and private sectors to ensure positive financial, social and environmental returns to potentially address household air pollution at scale. If health was the dominant rationale for driving these programs, however, the priorities would have been

driven by health outcomes and would target at-risk populations accordingly, as is the case for the health arena generally. In the delivery of vaccines and other basic health services to the poor, for example, the approach is not primarily a local market approach. It is understood that the health benefits of immunization are a beneficial social investment and that public policy should ensure an appropriate outcome (if needed, through provision of free or subsidized vaccines, for example).

3. Making clean available

There are clean cooking solutions to replace the use of solid fuels that have existed much longer than IBC programs. Indeed, from essentially zero in the late 1800s, more than 60% of the world’s population (over four billion people) cooks with liquefied petroleum gas (LPG)/piped natural gas (PNG) and/or electricity. In the currently developed countries, this transition occurred a century ago or more and was mostly driven by normal market mechanisms, although often facilitated by public policy, particularly in the power sector. In this way household cooking shifted in North America and Europe, for example. Indeed, the common American saying ‘Now you’re cooking with gas’ originated as an advertising slogan by gas companies late in the 19th century designed to lure women away from cooking with coal or wood to a modern efficient and aspirational fuel. Many marketing approaches that are having a renaissance today were applied, including zero interest loans to encourage the penetration of gas appliances as well as heavy door-to-door marketing (Smith 2010). These sources are also increasingly widespread in the developing world via normal business channels to the growing middle class (although often with some subsidy).

The promotion of gas and electricity as household fuels has not, until quite recently, been linked to the health agenda surrounding continued use of biomass. Primarily in India starting in 2015, but also beginning in a few other countries, however, there have recently been major government-led programs launched to enhance the use of LPG driven in large part by health concerns.

We have suggested elsewhere that this pathway of promoting what is well established to be clean already could be seen as working harder to ‘make clean available,’ which should be taken up even more strongly as it offers a way to bring clean cooking to billions more as it already has to so many (Smith and Sagar 2014). It also has delivery systems already in place to operate at the scale required.

3.1. Cooking with gas: a second revolution

In the middle of the last century, some lower middle income countries (LMICs) instituted major policy initiatives to promote LPG use among their poor (Troncoso and da Silva 2017).

3.2. An early success: LPG in Brazil⁸

Brazil's population in 1936 was approximately six times less than it is today, i.e. 36 million people living mostly in rural areas. Fewer than one million lived in the largest cities of Rio de Janeiro, São Paulo and Recife (in the northeast), which were the only places using piped gas for cooking and heating and then only in central areas. The others and all other areas in Brazil used firewood and charcoal for cooking. LPG was introduced that year, using the same bottles of methane to be used by the Hindenburg dirigibles, although use of the gas was discontinued after one of the airships was destroyed by fire (da Silva 2007).

In 1939, only 395 households in Rio de Janeiro used LPG (less than 0.1% of the households in the state at that time), but thanks to a successful marketing campaign that number reached 5160 in 1942. From then on, companies such as Standard Oil entered the market and consumption reached 10 000 tons of LPG in 1949 compared to 30 tons in 1938. The main driver was the fact that gas stoves were imported directly by the company and supplied along with the gas connection. The strategy was to donate gas stoves to foster natural gas taking the place occupied by fuelwood and charcoal in Brazilian households. As the result, the gas companies presented an idea of evolution whose apex was gas, relegating fuelwood to obsolescence by this modern and cleaner lifestyle. Also, there were sanitation and modernization campaigns in urban areas, in which gas stoves were illustrated in magazines and other media outlets as instruments to improve family health and to decrease working time in kitchens.

The LPG subsidies started in 1973 and were in place until the year 2000. During the 1990s, the LPG price policy began to be adapted to the introduction of a market economy, initiating a gradual process of price liberalization and withdrawal of subsidies at the end of 2000. Between 1973 and 2000, fuelwood consumption decreased by about 65%, which shows the success of government intervention at replacing wood-based energy with LPG in Brazilian households (Jannuzzi and Sanga 2004).

The expansion of LPG use in Brazil is due to a combination of intense urbanization processes and of governmental intervention based on price regulation and subsidies. In 1920, Brazil was a rural country; the country's urbanization rate increased from 26% in 1940 to 84% in 2010, and it is expected to reach 90% by 2020.

In 2014, there were less than ten million people relying on the traditional use of biomass for cooking, which corresponds to approximately 5% of the country's population. Currently, the majority of Brazilian citizens live in urban areas and large cities. The last comprehensive

survey on household composition and expenditure—the 2009 Consumer Expenditure Survey (Pesquisa de Orçamentos Familiares)—shows that 16% of Brazilian households own a stove that uses fuelwood or charcoal for cooking. The survey also shows that 59% of these cooking stoves are located in rural areas of the country. Currently, there are 5 570 municipalities in Brazil, of which only 227 (e.g. less than 1%) have no local LPG distributor.

The distribution of LPG in Brazil is an activity regulated by the Brazilian National Agency of Petroleum, Natural Gas and Biofuels (ANP). The distributors receive the product from the refineries and supply the LPG resellers or sell directly to large consumers in industry and commerce through tank trucks. More than 190 bases located in the five geographic regions of Brazil give support to this operation.

3.3. An emerging success? LPG for the poor in India

Starting in 2015, the Government of India (GoI) and the three oil marketing companies (OMCs) that sell the most LPG in the country embarked on three major programs to actively promote LPG to the poor—each one pioneering, aggressive and relying heavily on both sophisticated social marketing and what is summarized in India as 'JAM' (financial inclusion through access to banking facilities (Jan Dhan), the 'Aadhaar' card as a universal ID and cellular phones).

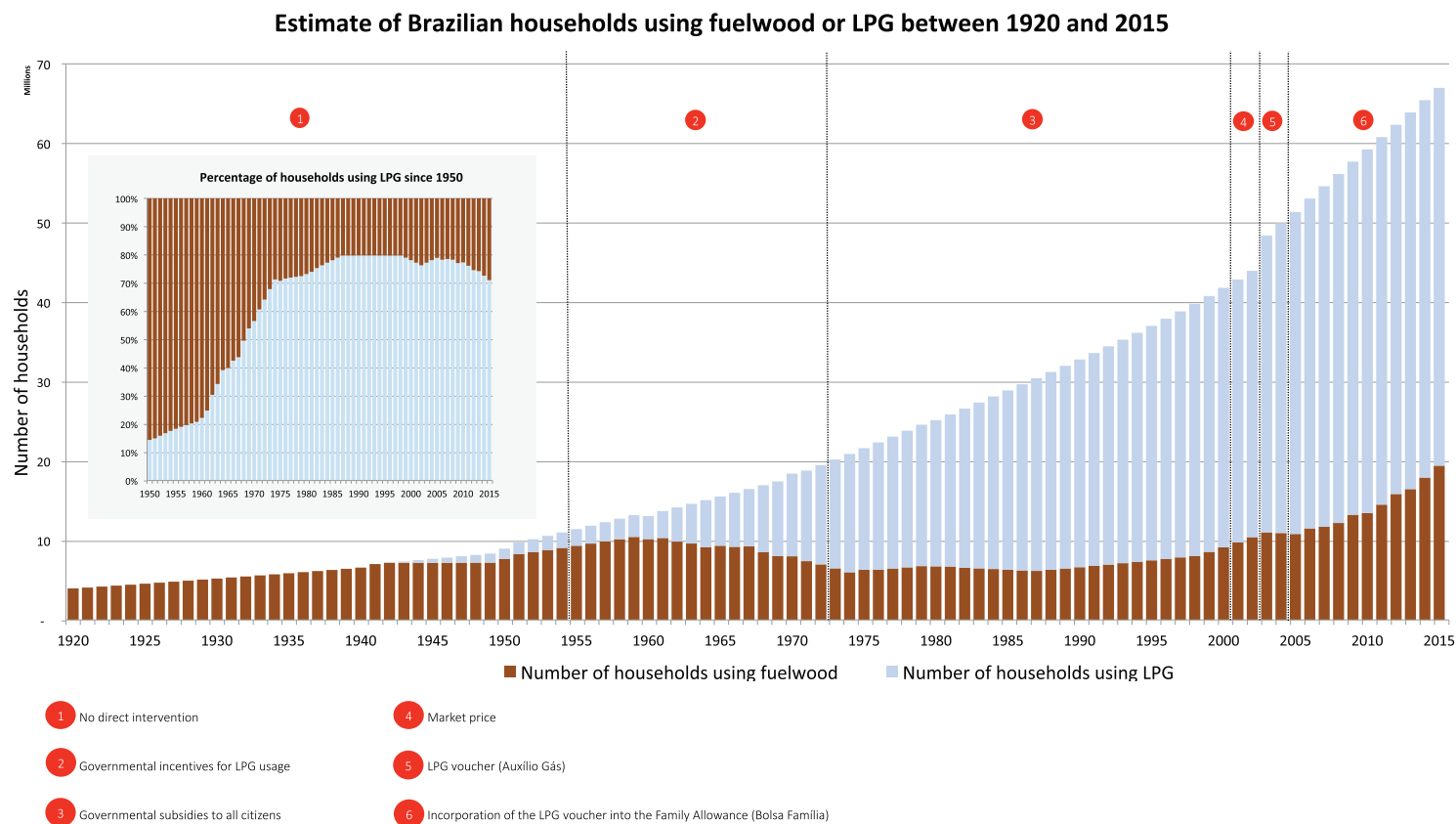
The first program, *Pahal*, shifted to making subsidized fuel payments directly into people's bank accounts thus enabling the sale of all LPG at market rates, greatly reducing diversion of LPG to the non-household sector. The second, 'Give it Up,' (GIU) persuaded middle-class households to voluntarily give up their subsidies to connect the poor through the companion 'Give it Back' campaign, with a website that showed the name of the poor person who benefited from each subsidy that had been given up (Smith and Sagar 2016). As of June 2017, over 10 million people had 'given it up.'⁹ The third program, *Pradhan Mantri Ujjwala Yojana* (PMUY), underway now, aims to provide free connections¹⁰ to a total of 50 million poor households by 2019 with 25 million already installed by July 2017¹¹. This has the potential to have a significant impact because many households can afford the monthly subsidized cost of LPG, but do not have cash upfront to pay for the connection costs—including the deposit on the LPG cylinder and the stove itself

⁹ (<http://mylpg.in/index.aspx>) Accessed: 20 June 2017.

¹⁰ 'Connection' has a specific meaning in India—a formal account established with a distributor for which a fee is usually required to cover the deposit on the initial cylinder, hoses, regulator, etc. Only through such a connection does a customer have access to subsidized LPG. These connection costs can be a barrier to poor households and are thus covered in the new government programs. Stoves can be obtained independently or by zero interest microfinance in all states, or from state or charitable funds in some.

¹¹ (<http://pib.nic.in/mobile/mbErel.aspx?relid=167449>) Accessed: 6 August 2017.

⁸ Much of this section is based on 'GLP Os pioneiros: meio século de história' Câmara Brasileira do Livro, São Paulo, CL-A Comunicações S/C Ltda, 1987.



Source: Prepared by the authors based on data from Jannuzzi (2004), Morais (2005), Uhlig (2009), MME (2010–2016), IBGE (2016), and EPE (2017)

Figure 1. Major phases in the Brazilian LPG program from 1920 to the present day. The usage data represents a different metric than that used by the WHO in the Global Burden of Disease assessment, which shows higher numbers of households using LPG in Brazil (Bonjour *et al* 2013). This is partly due to different databases being used, but seems mainly to be understood as the values in this figure representing the equivalent number of households solely using LPG, while the WHO database can be interpreted as those households using at least 51% LPG. The difference between these two numbers is one measure of the ‘stacking’ being undertaken by many households, i.e. continued use of wood as LPG comes in. From the Brazilian Energy Balance, Ministry of Mines of Energy, Brasília, years 2010, 2011, 2012, 2013, 2014, 2015 and 2016.

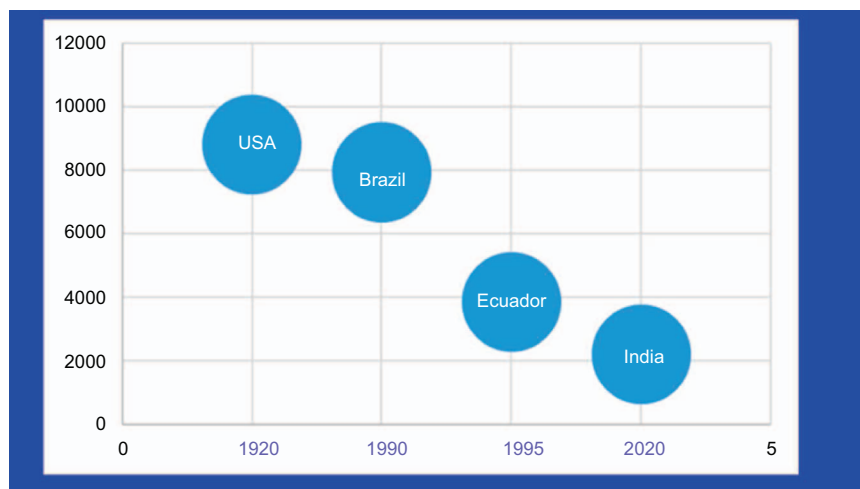


Figure 2. A rough ranking of the point when 80% of household fuels started to be supplied by gaseous fuels in four countries over the 20th century by GDP/capita in 2010 US dollars. Even though the ranking is not precise, due to data difficulties, it is clearly a downward trend, with India achieving this objective with a real GDP/capita about four times lower than the US did, albeit 100 years later. An analysis by PPP-corrected GDP shows smaller differences, but, as an internationally traded commodity, LPG should arguably be evaluated to levels between the two metrics.

(Smith 2017)—although there are remaining questions about the level of LPG uptake by those who have received a connection (Kishore 2017).

The result is a remarkable increase in the historically modest expansion of LPG connections. Although the 6%–7% growth in connections continues for the middle class, now 6%–7% more occurs among the poor through GIU and PMUY. This is thus double the old rate, albeit only now for a bit more than two years. The country now expects to cover more than 90% of all households with clean cooking by early next decade, although the official target is currently 80% by 2019. This would be a huge transformation in the household cooking energy space of any country, but especially so for one of India's size, and it is due to innovations of several kinds in policy measures.

Notably, this push did not come directly from the health or environment sectors, which do nevertheless benefit. Indeed, over time we can expect less ill-health in village households among women and men due to the range of diseases associated with cookstove smoke, with particular benefits for children due to lower pneumonia rates and for newborns due to a reduction in the rate of low birth weight (Smith *et al* 2014).

One of the lessons of the LPG experience in India is the implication of scale. With 18 700 local distributors, each with 20–40 employees operating house to house, and plans to hire 10 000 more distributors underway, the LPG industry will soon have an army of half a million people outside the cities to promote and service its product locally¹². When combined with a well-functioning infrastructure from port to neighborhood¹³, a high degree of quality control

and transparency (for example, a website with every LPG beneficiary under the GIU scheme) and moving toward near universal cashless transactions via JAM, it seems likely that this transformation will be sustained. It has also created a substantial number of jobs and contributed to the national economic agenda. Indeed, the PM's chief economist has noted that 'LPG is leading the way' in bringing the rural poor into the main economy¹⁴.

The 1.2 billion USD devoted to the PMUY program is a small fraction of other major national subsidy programs, such as the rural employment scheme and the food subsidy scheme (Bose 2017, Chakrabarti *et al* 2016). It is hard to say that it is expensive, particularly when it is accompanied by the more focused targeting of subsidies. Indeed, it would seem that the program can soon claim to be a social investment, not a subsidy. Both come from the taxpayer, but the former has a very different connotation when focused on the poor.

The time period and level of economic development showing when three countries with aggressive LPG policies reached/will reach substantial coverage of clean cookfuels is presented in figure 2 (along with data for the United States). It shows the GDP/capita at the approximate date in which each achieved or will achieve 80% penetration of LPG and/or natural gas fuel. Note that the US had a \$8800 income (in 2010 dollars) at the time, with each of the other three reaching—through policies and subsidies of different kinds—80% penetration at lower and lower incomes, with India poised to achieve this milestone by 2020. At that time, it will have an income per capita some one-fourth of what the USA had 100 years earlier.

¹² Personal conversation with MoPNG officials.

¹³ Many urban consumers receive refills at the household and this being so for everyone is a goal of the Ministry, although it is difficult

to achieve in many rural areas where refills are often provided at the village level.

¹⁴ LPG Conference, MoPNG, Bhubaneswar, September 2016.

4. Clean cooking and climate: getting the calculus right¹⁵

Although gas and electric options can significantly reduce household air pollution and the attendant health impact, they do result in some greenhouse gas emissions, either through direct fossil fuel combustion in the case of LPG/PNG or indirectly through the current dependence of most electricity generation systems on fossil fuels. Unfortunately, many development agencies seem to believe this conflicts with the other major agenda, i.e. countering climate change, as evinced by a lack of focus on promoting LPG as a clean cooking option in the face of the limitations of IBCs in achieving health outcomes. This has led to a lack of focus on (and sometimes opposition to) the ‘make clean available’ agenda, either actively or through passive neglect, in most major bilateral donors, development banks and large private foundations.

We make the case, however, that when the situation is examined carefully, there are essentially no circumstances in which the scale of the climate impact, if any, from a major substitution of biomass by LPG could be considered sufficient to warrant imposing barriers on its dissemination as widely as possible from the health side (Smith 2002, Smith 2014).

In terms of climate, biomass comes in two major types: sources that are harvested renewably, such as agricultural residues, and in many areas fuelwood, which is harvested non-renewably thus potentially increasing deforestation or at least putting pressure on biomass resources. Estimates are that some 30% of fuelwood is harvested without being replaced (non-renewably) worldwide, although with wide variation (Bailis *et al* 2015). The carbon in this wood is released into the atmosphere in the same net climate-altering mode as carbon in coal or petroleum, i.e. essentially a fossil fuel, although with carbon that is more recent in origin.

Biomass combustion produces methane and N₂O, both included in the Kyoto portfolio on major GHGs as well as ‘non-Kyoto’ SLCFs, including the gases carbon monoxide (CO), non-methane volatile organic contaminants (NMVOCs), nitrogen oxides (NO_x), sulphur oxides (SO_x) and black carbon particles. In addition, biomass burning creates so-called organic carbon particles, which have a net cooling effect. Here the calculus turns on how the different non-CO₂ emissions from biomass stoves are counted. Most analyses still rely on the 100 year global warming potential (GWP) developed by the Intergovernmental Panel on Climate Change (IPCC) for the Kyoto Protocol in 1997 to account for the other major combustion-related GHGs (even if these values have evolved over time in subsequent IPCC assessments);

the situation for non-Kyoto SLCFs is more complicated since there are no ‘official’ GWPs. A shorter time period (such as 20 years) focuses attention on nearer-term climate change, shifts more emphasis to the shorter-lived climate forcers, and thus favors clean combustion even more.

A life-cycle analysis performed by the United States Environmental Protection Agency (USEPA), which compared 100 year CO₂-eq emissions per meal in India across fuels, including estimates of the impact of several important SLCFs, including black carbon (Cashman *et al* 2016), found traditional renewable biomass fuels to produce 50%–66% of the CO₂-eq of LPG. An analysis of 20 year warming found that LPG had fewer emissions under Indian conditions when all Kyoto gases were included, but no black carbon (Smith *et al* 2005). In 2000, a sophisticated comparison of the relative global warming impact of the emissions of all major greenhouse species, including SLCFs, in the year 2020 found the biomass used in cookstoves to be the second largest greenhouse sector globally after on-road transport (Unger *et al* 2010).

If we ignore the non-CO₂ climate-active gases and particles emitted as well as the CO₂ emissions from coal and non-renewable wood, to focus only on the roughly remaining 60% of today’s solid fuel cooking (about 1.6 billion people; Bonjour *et al* 2013), which seems to come from renewable fuelwood, how does the resulting CO₂ penalty from LPG stack up compared to other global GHG sources? If all 1.6 billion converted to LPG, the total annual extra CO₂ emissions would be of the order of 0.2 billion tons CO₂/year. To put this into context, total global emissions from fuel combustion were about 32 billion tons in 2014 and have been growing at an average of 2% annually for a decade (IEA 2016).

Emissions from the transport sector were over 7.5 billion tons in 2014 (IEA 2016a). In fact, from commercial aircraft alone worldwide, emissions were 0.78 billion tons in 2015¹⁶, and unlike cooking, demand for flying is growing rapidly.

In India, transport alone is currently responsible for about 0.23 billion tons of CO₂ but is growing annually at 7% (IEA 2016a). If the annual growth rate were to be lowered to 6%, the reduction in annual CO₂ emissions by 2025 would be sufficient to compensate for the CO₂ produced by all LPG needed to replace renewable biomass use in households.

Thus, the shift to LPG cooking globally among the poor would be equivalent to far less than one year’s growth in the global total and unlike other types of demand, even in developing countries, cooking energy demand is slow to grow in households, given that household size is declining everywhere and the number of meals cooked is not likely to increase.

¹⁵ For a more detailed examination of this issue, see Bruce *et al* (2017).

¹⁶ (www.atag.org/facts-and-figures.html) Accessed: 6 August 2017.

Although not discussed further here, we note that similar arguments apply to electrification, even if powered by coal (Smith 2014). Indeed, the argument is probably even stronger due to the many other social benefits that are brought about by electricity in addition to clean cooking. Even where electricity is currently made with coal, its use in induction stoves would only create a miniscule extra addition to CO₂ emissions. Replacing all biomass cooking by coal-fired electricity, for example, would produce only 3% of the CO₂ released by the OECD power system.

5. The holy grail: electric with renewables?

The appropriate electric technology for clean cooking now seems to be in hand. Electric induction stoves, the first completely new cookstove technology in a hundred years, has recently come onto the scene in a large way in some parts of the world. Where there is reliable electric power, it offers a leap forward in completely clean household alternatives. For example, Ecuador is working to change every stove in the country to induction through a major government program, albeit one driven largely by the desire to use their own hydroelectric resources instead of imported LPG.

5.1. The induction stove program of Ecuador¹¹

The Ecuadorian Efficient Cooking Plan (ECP) for clean cooking aims to change three million LPG-based stoves to induction stoves, as the first energy policy program to introduce time-saving, energy efficient, clean and inexpensive cooking facilities for an entire country. The ECP is linked to a change in the energy mix, which seeks energy sovereignty and access to clean energy for Ecuador. For this purpose, it was necessary to invest in new infrastructure for hydroelectric power plants. This is because a low electricity price is needed to make the change attractive. In the case of Ecuador, more than 80% of electricity will be generated by less-expensive hydroelectric power.

For all these changes, a large amount of state investment was necessary. In the case of Ecuador, the government is investing US\$11.6 billion in new hydroelectric power stations and transmission infrastructure by 2022. The Ecuadorian government estimates an investment of US\$6 billion in hydropower plants, US\$1.2 billion in improved transmission infrastructure, US\$3.4 billion in household distribution, and US\$1.1 billion in the ECP and the National Efficient Electric Heater Program. This represents 11% of national GDP (Villacís *et al* 2015). To pay for these contracts, between the years 2009 and 2016, the Ecuadorian government has undertaken four contracts with China. The final amount is about US\$4 billion, which is related to the sale of an anticipated 200 million barrels of

petroleum. It is assumed that part of the money for these contracts has gone to the improvement of the electric grid and ECP.

It is necessary to take into account that the Ecuadorian government is promoting induction stoves to reduce the consumption of subsidized LPG. Among the general population, for domestic use a 15 kg bottle of LPG costs US\$1.60 (official price), while in neighboring countries (Peru and Colombia) this price is on average thirteen times higher. The total cost of this subsidy to the government was about US\$690 million per year, with approximately 5% of subsidized LPG lost to smuggling and 15% used for non-household purposes. In addition, approximately 78% of Ecuador's bottled LPG is imported, which creates major dependency and a significant outflow of national funds abroad.

To accommodate induction stoves, the electric distribution network requires an adjustment, especially at the level of energy distribution—transformers, primary feeders and connections. Large cooking loads inject excessive harmonics into the electrical network and can result in adverse effects on power quality (Kit *et al* 2012). Achieving an appropriate coincidence factor could avoid electrical grid problems such as the overheating of conductors and the mechanical oscillation of electrical devices, which would affect the operation of the distribution network.

The ECP is only aiming to replace LPG in the residential sector. The industrial and commercial sectors do not take part. Families can simply register with the ECP with a copy of their lighting bill and proof of identity. The family can also access financing through the local electricity company over 72 months. In addition, the electricity company will install a 220 V meter at home, also with financing.

In 2014, the government of Ecuador was planning to purchase induction stoves in four zones for \$265 and two zones for \$155, and it was intended to add a set of cookware composed of three pots and a pan for \$35. All stoves and cookware were designed and tested for Ecuadorian conditions. In addition, it was intended that the most disadvantaged families in Ecuador, numbering a little more than 50% or about 2 million, would receive the stove for free through the ECP, while the next 22% would be able to purchase the stove with a 50% discount plus financing.

The induction stoves offered with the ECP have a limited electric power of 4 kW, which limits the electricity distribution network requirements. Customs tariffs of 50% are paid for induction stoves that are not offered by the ECP.

Currently, as part of the NECP, induction stove adopters receive a 100% subsidy on the initial 80 kWh consumed per month, which is thought to be sufficient for an average family. This subsidy will be maintained until 2018. In addition, the electricity cost for additional consumption is a subsidized rate of US\$0.092 kWh⁻¹. However, even with this subsidy the population shows some reluctance to migrate to induction stoves

¹¹ Much of this section is based on Martínez-Gómez *et al* (2016, 2017).

immediately. Currently, about 500 000 families are attached to the PEC—none of whom have acquired free or discounted stoves. In 2014, it was estimated for this stage that around 2 million families had induction stoves. The population see the costs related to changing the induction stoves above to maintain LPG stoves and use subsidized LPG. In addition, in areas where the induction stove has been given as part of Plan Fronteras, the population maintains the LPG stoves because of the low cost of fuel.

Induction stoves are one of the most efficient cooking techniques available (Kastillo *et al* 2016). Because the power comes from new hydroelectric power plants, the energy demand of the country should actually decrease until 2032. In addition, the equivalent CO₂ emissions should reduce since the electricity comes from hydropower—although GHG emissions per kWh from hydro in Brazil range according to power density and the amount of flooded vegetation (Dos Santos *et al* 2006). Presumably the new dams in Ecuador, however, will not produce much flooded vegetation, because most are located in the highlands, between the Andes and Amazonian Ecuador.

Induction stoves have the advantage of being safer and more energy efficient compared to traditional stoves, which should stimulate users to change from traditional to induction stoves. Traditional cooking is strongly rooted in the habits of Ecuadorians, however, so effective incentives are also required to achieve the transition to electricity. In addition, the government of Ecuador has carried out marketing through advertisements on television, radio, social networks and websites. Furthermore, politicians, including the President of Ecuador and the Minister of Electricity and Renewable Energies have explained the ECP in different media communications; the Minister has also attended workshops to show how to cook with induction stoves.

The high subsidizing of LPG represents a great barrier to changing fuel in Ecuador, as society has become accustomed to a high subsidy and consequent inefficient use. Now, however, it seems the country may have found its way to a new system that benefits the poor and leads the country to self-sufficiency in household fuels, although it is one that requires substantial effort and excellent timing.

Once connected to the power grid, however, the power source can be shifted to solar or other renewables over time; this sets up the households for the long-term future.

6. Reshaping the clean cooking agenda

We suggest that the clean cooking agenda move away from a climate-first approach to recognize that the health impacts of HAP merit highest priority. This will not only serve to ultimately benefit those who do not have access to modern cooking energy services

but also build trust between various stakeholders in the climate and development arenas. The global community could apply its considerable resources and intellectual capacity to develop more productive ways of linking the climate and development domains. In this way it can place the climate problem in the context of the greater sustainable development challenges facing humanity.

In addition, traditional biomass users are generally quite poor and have hence produced historically low emissions, so in a sense they have already contributed to climate protection, even if in an involuntary fashion (Sagar 1999). So it is just as well that they are able to benefit from limited fossil fuels that can be used cleanly and efficiently. In fact, their link to the climate arena really should be seen as one where the industrialized high-emitting world owes them a 'natural debt' (Desai *et al* 2015), and therefore it would be appropriate to use a part of the climate finance flow to help the most disadvantaged groups.

As the framing of the household cooking issue shifts from an energy or climate perspective to health, the ethical picture shifts as well. As much as possible, the provision of health intervention (vaccines, antibiotics, antiretroviral drugs, clean water, etc) attempts to treat everyone's health as equal—we do not push approaches in rural areas that would be completely unacceptable in urban settings. LPG and electricity are acceptably clean for use by rich and poor worldwide, unlike the current generations of advanced biomass stoves, which would not be acceptable in urban areas. They are just not clean enough.

We believe the time has come for well-meaning organizations to reassess the deployment of cooking systems that the people in these organizations would never use themselves. Perhaps it would be justified if there was no knowledge of anything else, but we now have all the evidence needed showing that IBCs are not acceptably clean for people while gas and electricity are. Furthermore, 60% of the world uses the latter energy sources for all cooking already, essentially proving their viability.

As a CO₂ molecule released anywhere has the same climate impact as one released anywhere else, are the cooking habits of the poor really the best way to address climate action? No matter how cookfuel LPG is accounted, it is no more than a small part of the global climate picture. It is difficult to argue against the proposition that it is the global upper and middle classes (in rich and poor countries) who cause climate change, not the cooking of the poor.

In this vein, LPG, PNG and induction stoves powered by fossil fuel electricity could be seen as a bridging approach to a more sustainable future. Ideally, over time, one would promote cooking solutions that fully protect human health and the climate, though the interim solution should not be one that sacrifices human health for marginal or even zero gain for the climate.

In fact, gas—mostly in the form of natural gas—is already serving as a transition fuel for the modern world. It is helping us move past coal, the worst of the solid fuels in terms of both health and climate. In the end, however, most observers believe that large-scale energy solutions for society will largely come from electricity made of renewable sources (e.g. Edenhofer *et al* 2012). Similarly, a parallel transition can occur for poor households using solid biomass. In fact, what better use for a fossil fuel (whether gas or coal-derived electricity) than the one with the highest social value, i.e. cooking for the poor?

In order to best facilitate this reshaped clean cooking agenda, we suggest three categories of focus.

6.1. Improving delivery models

Whenever new technology of any sort is adopted, it rarely fully displaces the previous method instantly, as old habits die hard. High usage is needed, however, as well as a reduction in use of the old polluting technology, for full health benefits to be obtained. As LPG and induction cookstoves seem nearly universally aspirational, it would be useful to focus research and action agenda on ways to enhance access by making these clean fuels and technologies available and shortening the ‘stacking’ period, in stove parlance, when both old and new stoves are used (i.e. to substantially reduce the use of biomass). This is typical for health interventions, where it is not enough just to deliver condoms, bed-nets, institutional delivery facilities, etc, but where it is also necessary to provide ways of incentivizing people to use them and to stop any unhealthy traditional practices.

This may mean ensuring that a connection and stove (whether LPG or electric induction) is easily available and at zero or affordable cost for the poor; it may mean fuel subsidy levels tailored to populations in various economic strata and various risk levels (e.g. pregnant women); and it may mean ensuring that supplies of clean fuel (LPG or electricity) are steady rather than sporadic. It may also mean innovative public outreach campaigns to help the populace understand the benefits of switching to clean cooking; this could allow factors, such as inertia and social barriers that often prevent the uptake of new technologies, to be overcome. In fact, it would also be important to understand who to target within the households and communities—and tailor the messages to these actors. Such efforts can build on the programs and lessons learned from public health and the other relevant experiences of various countries.

6.2. Strengthening finance for clean cooking

IBCs have been seen as particularly attractive since the operating costs are negligible, in principle, since biomass may be available free or cheaply (although the reality may be very different in many cases). In the case of LPG or electricity, there is both the initial cost of the transition (establishing a fuel/electricity supply and

procuring a cookstove) as well as the operational costs of recurring energy use through consumption of LPG and/or electricity. Most poor people may not have sufficient finances available to cover both (or either), and therefore may need some subsidies (as is the case in health, as mentioned earlier).

India has initiated several innovative ways to promote and finance extensive expansion of LPG, including widespread application of IT systems and creative retargeting of subsidies into avenues that can be better characterized as social investments. But beyond domestic resource mobilization, there may be international possibilities linking together the climate and HAP domains in creative ways, including, for example, using the revenues raised from a tax on airline travel or gasoline use globally to fund access to clean cooking energy for the poor, while contributing to the mitigation of the growth of these GHG emissions sectors. Similarly, a tax on luxury electric appliances could be used for a similar purpose. The common theme here is linking the energy use of the well-off to energy access for the poor, thereby also promoting climate equity. Yet another possibility could be global competition for the most innovative policy to couple climate mitigation and clean cooking.

6.3. Enhancing technological options

While LPG and induction cookstoves already exist, it should be possible to further improve their efficiency. Indeed, at the end of the Obama administration the USDOE had pending efficiency standards for US standard cooking appliances that would not only save billions of dollars for consumers in saved fuel but also reduce CO₂ emissions by several hundred millions of tons (USDOE 2016). A push for more efficient cooking appliances would yield benefits, not only for the poor, but also contribute to the reduction of cooking-related GHG emissions even from developed countries.

One can also imagine that an effort to optimize a solar-PV and induction cookstove combination (which may also require new energy storage solutions) may yield useful results in terms of developing technologies that can serve in remote areas that the grid may not be able to reach in the near term (or at all). Such a technology solution may also have the potential to piggyback on the enormous solar PV and enhanced energy storage push across the world, while also providing other energy services in remote/poor households as well. This can be explored either through the standard route of targeted research and development, or perhaps more relevantly, through an innovation prize and/or an advanced market commitment approach to induce innovation in these areas.

At the same time, it is worth continuing efforts to ‘make clean available’ by developing a truly clean-burning biomass cookstove, for example, through a global innovation prize, as envisaged by us earlier (Sagar and Smith 2013), in a way that is driven by health rather than climate.

7. Conclusion

The provision of clean energy services lies at the intersection of climate, health and energy access, and therefore presents an important test case for how developing countries, working with the global community, can balance these overlapping but sometimes competing agendas. In the end, the most robust solutions are likely to be those that satisfy multiple agendas simultaneously and pave the way for a sustainable and just world, and certainly not those that sacrifice developmental imperatives at the altar of small amounts of climate mitigation.

With this backdrop, the push for improved biomass cookstoves needs to be re-examined, given that while they deliver some climate benefits, they do not protect human health adequately. LPG, being clean, efficient and easily stored and transported in small amounts, is a one-time gift from nature that is available now. Let it be used for the highest social purpose—providing clean household energy to improve the lives of the very poorest among us, starting with women and children. Like gas in the developed world, however, it should be seen as a step toward using renewable electricity—the ultimate clean and sustainable energy source—for meeting household cooking energy needs.

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ORCID iDs

Kirk R Smith  <https://orcid.org/0000-0002-0439-1120>

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