What future for cooking with solid biomass? The benefits of improved stoves and micro-gasifiers

Many households in Kenya and Tanzania use firewood and charcoal cookstoves that have a low thermal efficiency[1] and produce high amounts of noxious emissions. This contributes to the overuse of forest resources and has adverse impacts on people's health. Improved biomass cookstoves are more efficient than regular ones and produce smaller amounts of harmful emissions. Policymakers are encouraged to promote improved firewood and non-carbonized briquette value chains, on account of their smaller carbon footprint. However, even the best briquettes biomass fuels emit more particulate matter during combustion than liquid petroleum gas (LPG). Health concerns cannot be ruled out. Therefore, recommendations given in this policy brief target the period of transition from biomass to modern energy services. ▶

Challenges of solid biomass

In East Africa, around 90% of rural and low-income urban households use either firewood or charcoal to cook their food. According to estimates, the transition from biomass-based cooking fuels to modern solutions, such as electricity or LPG, is likely to last several decades. Rural households prefer firewood, while urban ones favour charcoal. For example, charcoal provides 82% of the energy used by urban households in Kenya (Wanjiru et al. 2016). The high annual growth rate of the urban population (around 4%) leads to a continued increase in the demand for charcoal.

Inefficient pyrolysis

The problem with charcoal is that the process of pyrolysis, which transforms wood into charcoal, comes along with a massive loss of the wood's energy content: depending on the efficiency of the kiln, about half of the wood's caloric value contained is lost (Kammen and Lew 2005). Even if all other aspects (forest resource management, transport, and final combustion) are handled in the most

[1] Selected terms and expressions are explained in Box 1.

KEY MESSAGES

Improved cookstoves are more efficient and significantly reduce cooking time and fuel consumption compared with unimproved fireplaces and stoves. In addition, well performing micro-gasifier stoves help significantly reducing fine particle emissions.

High-quality non-carbonized briquettes as well as firewood are more eco-efficient than charcoal. This means that their carbon footprint, i.e. the amount of greenhouse gases that they emit, is smaller and consumer costs are low.

Despite these encouraging developments, field measurements reveal that liquid petroleum gas (LPG) still cause much less particulate pollution than improved biomass cookstoves. For this reason, people need to be supported in climbing up the energy ladder.

Box 1: Definitions

Carbon footprint: the amount of greenhouse gases produced by a human activity, expressed in carbon dioxide (CO_2). Greenhouse gases are responsible for climate change via the effect of global warming.

Carbon monoxide (CO): colourless, odourless, and tasteless gas consisting of one carbon atom and one oxygen atom. It is toxic to animals and humans when encountered in high concentrations. Breathing CO can cause headache, dizziness, vomiting, and nausea. If CO levels are high enough, it may result in coma and even death.

Particulate matter (PM): microscopic matter suspended in the air. PM penetrates into the lungs and may even pass through the lungs to affect other organs. PM is associated with various health issues, including irritation of the eyes, nose, and throat, coughing, chest tightness, shortness of breath, reduced lung function, irregular heartbeat, asthma attacks, heart attacks, and premature death in people with heart or lung disease.

Pyrolysis: decomposition of organic material at elevated temperatures in the absence of oxygen. It is one of the processes involved in charring wood, starting at 200–300 °C.

Thermal efficiency: in connection with cookstoves, thermal efficiency refers to the percentage of the fire's heat that is actually delivered to the cooking pot. A thermal efficiency of 40% means that 60% of the fire's heat is lost in the air.

Value chain: series of activities and processes from production to the utilization of a product or service. For example, it may include the procurement of resources, processing, transport, utilization, and disposal.

efficient possible way, a 50% loss of caloric value during pyrolysis means that the charcoal production process – and hence charcoal value chains – are resource-inefficient and therefore not commendable from an environmental point of view.

Indoor air pollution

Most households use firewood and charcoal stoves that have very low levels of fuel efficiency and emit high amounts of carbon monoxide (CO) or particulate matter (PM). Respiratory diseases due to indoor air pollution have become a worrying public health challenge. In 2004, the World Health Organization estimated that 14,300 people in Kenya and 18,900 in Tanzania die each year from respiratory diseases caused by indoor air pollution (WHO, Clough 2012). Charcoal is better than wood in terms of PM, but it emits more CO, which can be lethal in high concentrations.

What future for solid biomass?

Looking at the above challenges, are there any solutions that policymakers and development partners could recommend to urban and rural households? Adequate solutions should take into account people's current practices and preference for solid biomass fuels while helping to reduce health hazards from noxious emissions and environmental impacts. In addition, they should help to secure the incomes of more than one million people in Kenya and several hundred thousand in Tanzania who are currently deriving their livelihood from charcoal production or trade.

Improved wood and charcoal stoves

The research project Prospects for Biomass Energy (ProBE) (see page 4) conducted an inventory of biomass cooking technologies. The inventory shows that some improved wood stoves have a significantly higher efficiency and lower emissions than the traditional three-stones fireplace, thus helping to address the environmental and health challenges mentioned above. Improved charcoal stoves also have better values than the traditional metal charcoal stove, but improvements in terms of both efficiency and emissions are not as impressive as in the case of wood stoves, as elaborated below and illustrated in Figure 1.

Efficiency and speed

On average, charcoal stoves are slightly more efficient than wood stoves. However, if one factors in the losses incurred during pyrolysis (see above), the overall efficiency of firewood value chains is significantly higher than that of charcoal value chains, despite the slightly lower efficiency of wood stoves. With some exceptions, wood stoves are also much faster than charcoal stoves. Changing from a traditional three-stones fireplace to an improved wood stove can lead to significant improvements in efficiency and speed. For example, the Envirofit and Jiko Smart wood stoves have an efficiency of close to 30%, whereas that of the traditional three-stones fireplace is 12%, which means that only 12% of the heat produced by the fire is delivered to the pot. Efficiency and time gains are not as spectacular in the case of improved charcoal stoves. The best performance recorded in our inventory is at around 45% efficiency and 25 minutes cooking time, while the traditional metal stove has an

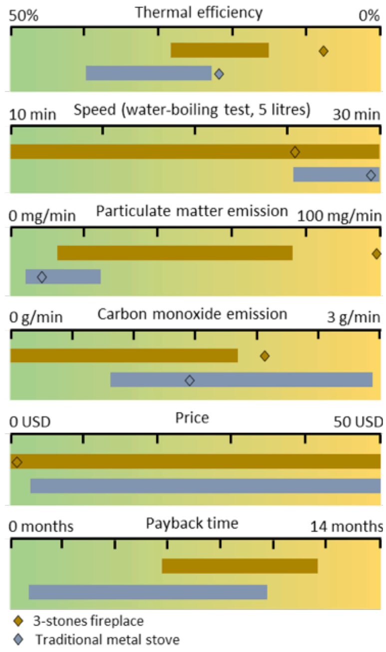

Figure 1: Performance of traditional and improved wood and charcoal stoves along six criteria: Efficiency, speed, particulate matter emissions, carbon monoxide emissions, price, and payback time. The green-to-orange gradient symbolizes decreasing performance from left to right. The brown bars show the approximate combined range of performance of 5 improved wood stoves: Maendeleo, Multi-purpose, Envirofit, Jiko Smart, and Mud Firewood Stove. The blue bars show the approximate combined range of performance of 5 improved charcoal stoves: Kenya Ceramic Jiko, Multi-purpose stove, Jiko Smart, Jikokoa, and Uhai.

approximate efficiency of 25% and completes the water-boiling test in around 30 minutes.

Health

The biggest challenge in wood stoves is the emission of health-damaging PM, which occurs at much higher rates than in charcoal stoves. Expectedly, the worst emitter is the traditional three-stones fireplace: it emits five to ten times more PM than some of the improved wood stoves (Jiko Smart and Envirofit M-5000), and 20 to 40 times more than most charcoal stoves. However, wood is better than charcoal in terms of carbon monoxide emissions. The Envirofit M-5000 performs best among the inventoried wood stoves, at 0.1 to 0.2 grams of CO per minute. The other improved wood stoves emit between 1 and 2 grams per minute, which is comparable to the performance of improved charcoal stoves (Jikokoa, Uhai, and Kenya Ceramic Jiko).

It must be noted that these emission values were measured in laboratories. Wathore et al. (2017) calculated that the average values for PM emissions are more than 3 times higher when measured in real-life settings than when measured in the lab. This is due to varying fuel quality and inappropriate handling of the stove. Consequently, under real-life conditions, even the best wood stove emits around 60 times more PM than an LPG stove. From a public health perspective, improved biomass-based cooking technologies must therefore be considered an interim solution during the transition to cleaner energy sources.

Costs

All charcoal and wood stoves cost between 0 and 50 USD. Interestingly, improved charcoal stoves pay off faster than wood stoves: Charcoal is more expensive than wood, and hence fuel savings lead to shorter payback periods for charcoal. The initial investment in a Jikokoa, Jiko Smart, or Uhai charcoal stove can be recovered within only 3 to 4 months. By contrast, the payback periods for the Maendeleo, Jiko Smart, and Envirofit wood stoves are closer to one year. The traditional mud stove is an exception among wood stoves, as it pays off after around 4 months only.

Micro-gasifiers

The ProBE project had a detailed look at top-lit up-draft (TLUD) micro-gasifier stoves (see Box 2), most of which take several fuels, including wood, briquettes, and pellets. Consequently, ProBE also investigated the efficiency of non-carbonized briquettes and pellets from farm residues and sawdust.

Efficiency and costs

TLUD micro-gasifier stoves, such as the Jiko Bomba in Tanzania or the M2 model of Wisdom Innovations in Kenya (Figure 2), are particularly interesting alternatives. They combine pyrolysis and combustion of solid matter within the same device, and they make use of the heat from both to sustain the cooking process (Roth 2014). This leads to high thermal efficiency and cleaner combustion, helping to reduce emissions. Wathore et al. (2017) calculated that, under real-life conditions, TLUD micro-gasifier stoves use up to 50% less fuel than a three-stones fireplace.

However, TLUD micro-gasifier stoves present two major challenges. First, they are expensive. Simpler models cost 25 to 50 USD; so-called forced draft models, which include an electrical fan, can cost up to 150 USD. Potential users will only adopt such stoves if they can be sure to recover their initial investment through reduced fuel consumption; if maintenance services are available in the region; if they are properly informed about the health benefits of clean indoor combustion; and if financing options are made available. Second, TLUD micro-gasifier stoves must be operated correctly in order to perform well. For example, PM emission values increase significantly if wood is not cut to the proper size and sticks out the top of the stove, or if the fire is lit from below instead of from above.

Emissions

Laboratory tests conducted within the ProBE project confirm the findings of Jetter et al. (2012) and other authors, according to which TLUD micro-gasifier stoves emit less PM than other improved stoves and massively less than traditional stoves. However, PM emissions can vary greatly, even in a TLUD micro-gasifier, depending on the quality of the fuel (Figure 3). Our tests show that very dry and fast-burning briquettes (such as sawdust briquettes B in Figure 3) produce substantially higher emissions than other briquettes. The tests also show that maize cobs are highly polluting in terms of PM when used in stove A, but very clean when burned in stove B. This is because they necessitate frequent refuelling, which, in the case of stove A, requires removing the top part of the stove – a manipulation that is not required with stove B and that leads to a surge in PM emissions. In light of these high variabilities, combinations of fuels and stoves need to be further investigated in order to propose the best options to consumers.

Box 2: Micro-gasifier stoves

Micro-gasifier stoves promise both increased efficiency and the possibility of combusting residual materials. Micro-gasifiers consist of a burner unit with a primary air inlet and a heat-transfer structure with a secondary air inlet. Most models follow the top-lit up-draft (TLUD) principle. Combustion in a micro-gasifier can be divided into four stages. (1) Drying: When the biomass reaches a temperature of 100 °C, the remaining moisture evaporates leaving behind dry biomass. (2) Pyrolysis: When the temperature reaches 300 °C, biomass is converted into volatile vapours and char. (3) Wood-gas combustion: The volatile vapours mix with oxygen provided by the secondary air inlet and are ignited by a spark or the existing flame. (4) Char gasification: The solid residue in the fuel bed is converted to ash. This stage is independent of wood-gas combustion and only takes place when oxygen is allowed to enter through the primary air inlet and react with the hot char (> 500 °C).

Figure 2: M2 Micro-gasifier stove of the Wisdom Innovation Company in Kenya during a water-boiling test conducted at the University of Nairobi in 2016.

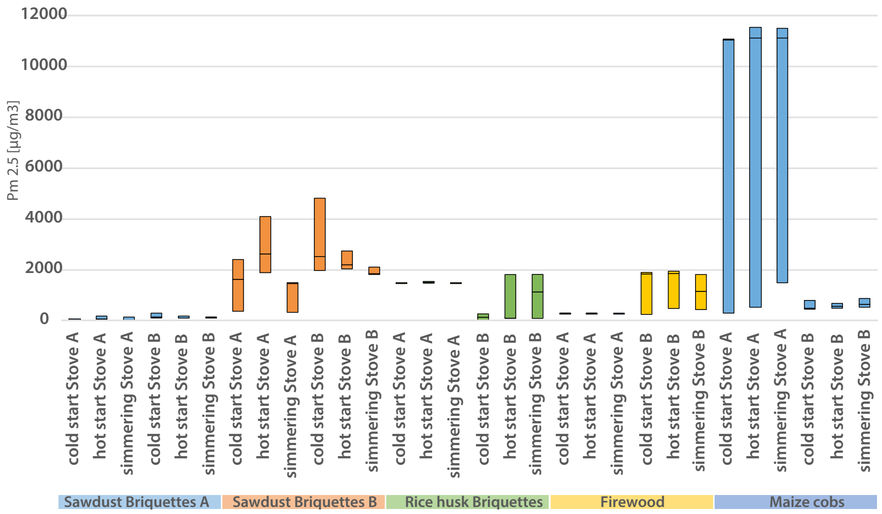

Figure 3: Particulate matter emissions of two TLUD micro-gasifier stoves (stoves A and B) using five different fuels (briquettes, firewood and maize cobs). Emissions are shown for cold start, hot start and simmering phases during a water boiling test conducted by the ProBE project at a laboratory of the University of Nairobi.

Policy implications of research

Gradually phase out charcoal

Biomass energy policies should acknowledge that charcoal value chains are resource-inefficient due to massive losses during pyrolysis, and that there are ways to reduce the current dependency on charcoal. Wood can be promoted as a sustainable source of cooking energy at the household level, at least until the transition to modern and cleaner options is accomplished. However, wood should only be promoted in combination with improved stoves that ensure better combustion and reduce particulate matter emissions.

Push micro-gasifier stoves

Biomass energy strategies and rural advisory services should promote top-lit up-draft micro-gasifier stoves as they have a high thermal efficiency and comparatively low emissions of carbon monoxide and particulate matter. However, context-specific factors might hinder the uptake of this technology. Therefore, attention should be paid to the availability of adequate fuels in the region, the purchasing power of potential user households, and the availability of microcredits to enable investments in the technology. Further, it is important to provide support and training in handling these stoves, as their advantages depend on proper use. We also recommend testing various models before introducing them in specific regions.

Integrate alternative fuels

Biomass energy strategies should pay special attention to high-quality non-carbonized briquettes and pellets made from woodchips, farm residues, sawdust, or woody biomass residues. Such fuels are eco-efficient, which means that they have a low carbon footprint and a low price. In general, however, policymakers should promote field testing of various combinations of top-lit up-draft micro-gasifiers with different fuels to help determining ideal solutions for specific contexts.

Further reading

Clough L. 2012. *The Improved Cookstoves Sector in East Africa: Experience from the Developing Energy Enterprise Programme (DEEP).* London, UK and Nairobi, Kenya: GVEP International and DEEP. http://www.energy4impact.org/sites/default/files/deep_cookstoves_report_lq_for_web.pdf.

Jetter J, Zhao Y, Smith KR, Khan B, Yelverton T, DeCarlo P, Hayst MD. 2012. Pollutant emissions and energy efficiency under controlled conditions for household biomass cookstoves and implications for metrics useful in setting international test standards. *Environmental Science and Technology* 46(19):10827–10834. http://dx.doi.org/10.1021/es301693f.

Kammen DM, Lew DJ. 2005. *Review of Technologies for the Production and Use of Charcoal.* Renewable and Appropriate Energy Laboratory Report. Berkeley, CA, USA: National Renewable Energy Laboratory, University of California. http://www.hedon.info/docs/Kammen-Lew-Charcoal-2005.pdf.

Roth C. 2014. *Micro-gasification: Cooking With Gas From Dry Biomass. An Introduction to Concepts and Applications of Wood-Gas Burning Technologies for Cooking.* Second, revised version. Eschborn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. https://energypedia.info/images/0/05/Micro_Gasification_2.0_Cooking_with_gas_from_dry_biomass.pdf.

Wanjiru H, Nyambane A, Omedo G.ß *How Kenya Can Transform the Charcoal Sector and Create New Opportunities for Low-Carbon Rural Development.* SEI Discussion Brief. Nairobi, Kenya: Stockholm Environment Institute – Africa and World Agroforestry Centre. https://www.sei-international.org/publications?pid=3021.

Wathore R, Mortimer K, Grieshop AP. 2017. In-use emissions and estimated impacts of traditional, natural- and forced-draft cookstoves in rural Malawi. *Environmental Science and Technology* 51(3):1929–1938. http://dx.doi.org/10.1021/acs.est.6b05557.

WHO [World Health Organization]. *Quantifying environmental health impacts: Country profiles of environmental burden of disease.* www.who.int/quantifying_ehimpacts/national/countryprofile/en.

The ProBE project

The research project Prospects of Biomass Energy (ProBE) in East Africa was part of the Swiss Programme for Research on Global Issues for Development (r4d programme; project no. IZ01Z0_146875). The project involved researchers and technical experts from the following organizations: Centre for Development and Environment (CDE), University of Bern, Switzerland; Centre for Training and Integrated Research in ASAL Development (CETRAD), Kenya; Quantis, Switzerland; Practical Action Eastern Africa; and Tanzania Traditional Energy Development Organization (TaTEDO), Tanzania. Between 2013 and 2017, the ProBE team analysed the prospects of pro-poor biomass energy value chains in rural–urban contexts in East Africa, based on case studies in Kitui County, Kenya, and Kilimanjaro Region, Tanzania.

Swiss Programme for Research on Global Issues for Development

The Swiss Programme for Research on Global Issues for Development (r4d programme) is a joint funding initiative by the Swiss Agency for Development and Cooperation (SDC) and the Swiss National Science Foundation (SNSF). The r4d programme supports research aimed at solving global problems with a focus on least developed as well as low- and middle-income countries. The r4d programme consists of five thematic modules and a thematically open module.

www.r4d.ch

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

FNSNF Swiss National Science Foundation

Authors

Centre for Development and Environment (CDE)
University of Bern (CDE), Switzerland. www.cde.unibe.ch
Albrecht Ehrensperger, Samuel Willi, Susanne Wymann von Dach

Centre for Training and Integrated Research in ASAL Development (CETRAD)
Nanyuki, Kenya. www.cetrad.org
Abigael Okoko and Boniface Kiteme

Practical Action Eastern Africa
Nairobi, Kenya. https://practicalaction.org/east-africa
James Gatimu and Jechoniah Kitala

Tanzania Traditional Energy Development Organisation (TaTEDO)Dar es Salaam, Tanzania. www.tatedo.org
Shima Sago and Jensen Shuma

Language editing: Marlène Thibault, CDE

Design, Layout, and Printing: Resources International

© The Authors 2017
This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) Licence. See http://creativecommons.org/licenses/by-nc/4.0/ to view a copy of the licence.

The views expressed in this policy brief belong to the author(s) concerned and do not necessarily reflect those of the partner organizations as a whole or of the funding organizations.

Citation: Ehrensperger A, Gatimu J, Willi S, Kitala JK, Okoko A, Shuma J, Sago S, Kiteme B, Wymann von Dach S. 2017. *What future for cooking with solid biomass? The benefits of improved stoves and micro-gasifiers.* ProBE Policy Brief 1. Nairobi, Kenya and Bern, Switzerland.

For printed copies, please contact:

CETRAD
Buttsons Complex Building
Off Hospital Road
P.O . Box 144 –10400
Nanyuki, Kenya
cetrad@cetrad.org

UNIVERSITÄT BERN
CDE CENTRE FOR DEVELOPMENT AND ENVIRONMENT

PRACTICAL ACTION

CETRAD