Cooking with electricity in Africa – A technical note on energy consumption

Author S Batchelor

This technical note draws attention that with the shift from biomass to electricity it is important to shift the framework of assessment. There needs to be a change of assessment from the predominantly laboratory based testing of improved biomass stoves for efficiency and lower emissions, to field based consumer experience of cooking processes for any new generation of electric stoves (ecookers).

With electric cooking efficiency is 'improved' in the control of the cooking process, the absence of need to 'keep the fires going', and the lower losses in transfer from appliance to pot. Therefore we cannot compare directly current fuelwood or charcoal consumption with the outcome of a household using an electric appliance for cooking.

Gamos Working Paper June 15

This briefing paper has been prepared as a part of ongoing research in Renewable Energy. In particular it is an output contributing to the SAMSET research project, the AGRICEN research project, the READ research project and the Low Cost Technologies research project. Each of these projects are partnerships funded by the UK Engineering and Physical Sciences Research Council (EPSRC), the UK Department of International Development (DFID) and the UK Department for Energy and Climate Change (DECC). On each project Gamos is a Co-investigator and collaborator. This paper also informs the proposition being Championed by Gamos that Solar electric cooking will be a cost effective, emission free option for resource poor households by 2020 (or earlier)

1 The challenge.

Approximately 3 billion people routinely cook with biomass (mainly wood or charcoal). 1.5 billion of these pay more than $10 a month for the purchase of their fuel[i]. While the details vary throughout Africa and Asia, the availability of $10 a month to fund an alternative zero emission fuel is a key opportunity.

Annually, 1.5 million people die prematurely of acute respiratory diseases from smoke and emission inhalation in households cooking with wood, biomass, and coal[ii]. When the debilitating effects of respiratory infection are taken into account, this rises to 4.5 million DALYs per year[iii]. Improving the efficiency of cooking (e.g. improved biomass cookstoves) offers only incremental reductions in emissions. Recent work suggests that emissions of particulates even from improved biomass stoves (with chimneys) are higher than WHO recommendations[iv]. Electric cooking gives zero emissions at the kitchen level and would save lives.

Cooking using traditional fuels also leads to emissions of greenhouse gases, and in certain areas it leads to localised deforestation. The UNEP estimates that these emissions represent 5% of total global warming derived from human activities[v], equivalent to some 1.75 Gt CO_2 eq/year.

The International Energy Agency expects slow progress in tackling these issues. Given the high rates of population growth, they estimate that in sub-Saharan Africa, fuel switching and the spread of improved biomass cookstoves together will result in only 10% fewer people by 2040 without access to clean cooking, with some 650 million still using traditional fuels[vi].

> *"The world has woken up to the serious health, environmental, and economic impacts of continued dependence on biomass for cooking. At the same time, rapid progress in technology and new financial mechanisms to support this sector have made real change possible."* (Rihot Khanna, The State of the Global Clean and Improved Cooking Sector, 2015[vii]).

And yet as the report progresses there is little reference to electricity as a potential modern fuel for substituting for biomass.

> *"Consider, for a moment, the simple act of cooking. Imagine if we could change the way nearly five hundred million families cook their food each day. It could slow climate change, drive gender equality, and reduce poverty. The health benefits would be enormous."* (ibid)

For electric cooking to provide a viable alternative to biomass, the cost and reliability needs to be right. Whilst the key benefits of electric cooking lie in improved health and reduced global warming emissions, neither of these can currently be monetised as benefits to consumers. Appliances need to be made available to consumers at a cost similar to current household budgets for biomass.

2 The technical arena of improved cookstoves

To tackle this problem a great deal of effort has been put into improving the efficiency of biomass cookstoves. 'Improved cookstoves' is development stream undertaken by many agencies.

In 2012, the Global Alliance for Clean Cookstoves published an inventory. Since then further work has been undertaken in both further technical developments and in terms of scaling the existing solutions. However as a key reference work, it is representative of how improved cookstoves are discussed – in terms of energy efficiency and lower emissions.

"Almost all of the short and medium-term outcomes of cookstove projects, particularly energy efficiency and reduced concentrations of smoke in the home, as well as the desired long-term impacts, including reduced mortality and poverty alleviation, are all tied to the technical capabilities of the stove."

Behind these statements lie technical tests. Most are based on the water boiling test – bring a set amount of water to the boil. "The WBT category includes any and all stove tests involving the boiling of water in a laboratory (i.e. WBT 4.1.2, WBT 3.0, Chinese Water Boiling Test, Indian Water Boiling Test, etc.). The specific information about the specific type of test is also in the inventory, but the larger WBT category is used for broad characterization of the test type."

However in a few cases there are more sophisticated tests where different intensities of burn are included in scenarios more akin to real cooking. “The HTP (Heterogeneous Test Protocol) category involves laboratory testing where stoves are systematically operated across a range of fuel loadings/powers and pot sizes. It should be noted that the CCT (controlled cooking test) or KPT (Kitchen Performance Test categorization was applied to some stove test results where the test protocol matched the general principles of these test types, even though the source authors did not refer to their protocols as a CCT or KPT. The UFT (uncontrolled field test) category includes any and all types of uncontrolled field testing and includes the Uncontrolled Cooking Test (UCT), for which performance is measured for single events (meals, boiling water, etc.) and longer tests of daily operational stove use.

The inventory illustrates how how ‘improved stove’ tests focus on energy use rather than on the way people use the stove. The figure below shows the distribution of test sets for the different protocol classes. “WBT versions are by far the most commonly used protocols, with field CCTs, KPTs, and UFTs providing the remainder of the test sets.”

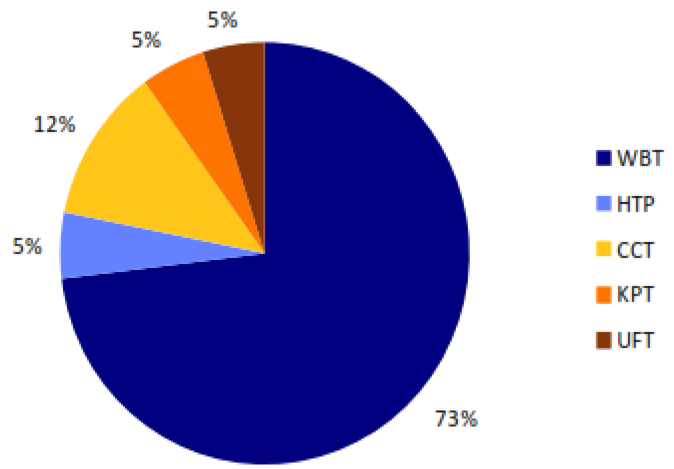

Figure 1 Percentage of test sets by protocol. (Stove Performance Inventory Report Berkeley Air Monitoring Group October 2012)

2.1 Documenting the efficiency and the emissions

In common with most other agencies that discuss the use of biomass, the focus (in the inventory) tends to be on the efficiencies of fuel conversion. Efficiencies (and by implication improvements) are claimed when biomass is consumed more effectively for example Figure 2.

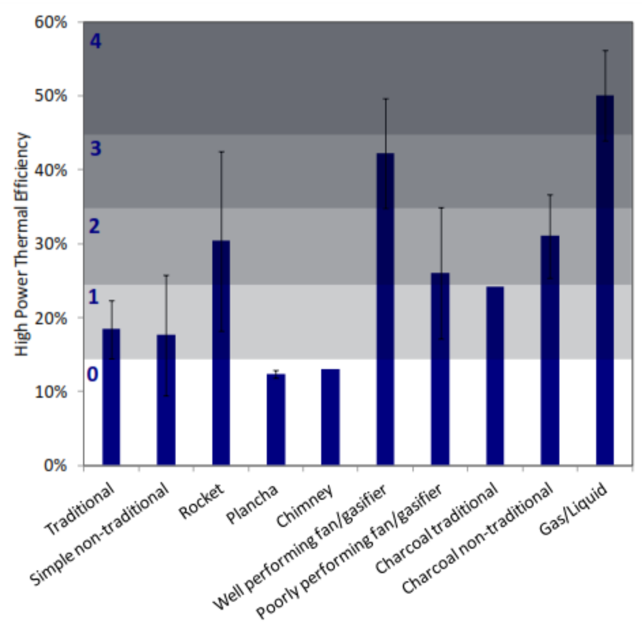

Figure 2 Thermal efficiency performance for key stove/fuel classes across the IWA Tiers for the VITA WBT. Error bars represent ± one standard deviation of the available tests sets. Tiers are indicated by blue numbers. Stove Performance Inventory Report Berkeley Air Monitoring Group October 2012

As discussed in the problem statement above, the other concern with a biomass stove is its emissions. Accordingly, the inventory uses the tests described above to log the emissions. For example figure 3.

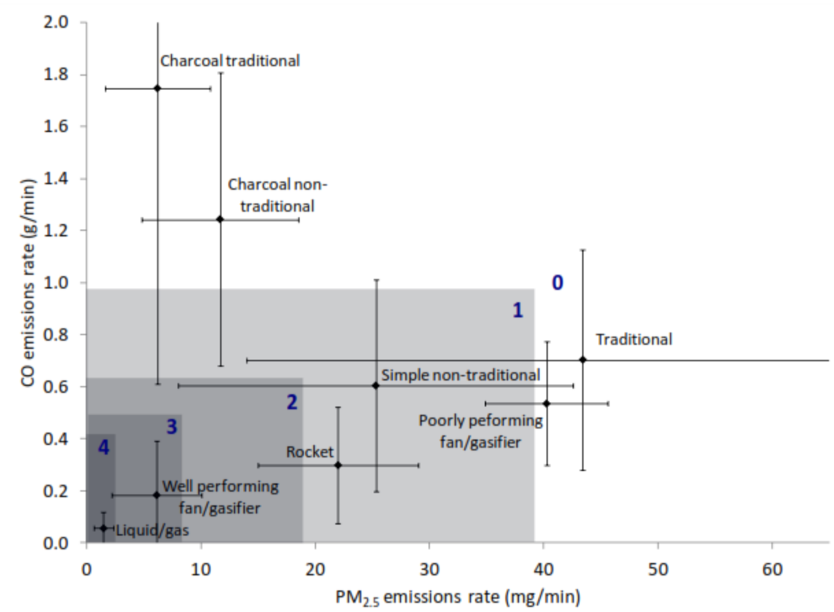

Figure 3 Indoor emissions performance for key stove/fuel classes across the IWA Tiers for the WBT. Error bars represent ± one standard deviation of the available tests sets. Stove/fuel classes with no error bars consist of two or less data points. Tiers are indicated by blue numbers. Stove Performance Inventory Report Berkeley Air Monitoring Group October 2012

When we consider cooking with electricity, these measures mean very little.

Differences in efficiency for a standard water test are marginal. Water can be boiled faster on a given stove if the pot ‘fits’ the hotplate ring better than another. Kettles, where the heating element is completely surrounded by the water are more efficient than a hotplate. However one cannot cook a meal with a kettle.

Similarly, the emissions comparison means little. In terms of kitchen emissions electricity is zero, unless one burns the food.

Therefore, when discussing the opportunity of electric cooking, we need more realistic tests. We need to know how people cook, the processes by which they cook and the resulting energy consumption across different electrical devices.

With electric cooking efficiency is improved in the control of the cooking process, the absence of need to ‘keep the fires going’, and the lower losses in transfer from appliance to pot. Therefore we cannot compare directly current fuelwood or charcoal consumption with the outcome of a household using an electric appliance for cooking.

3 Considering the energy people actually cook with.

While there are market studies on fuel consumption and the number of meals cooked, there seems to be little published research on the way people cook. There is of course a wide variety of dishes and even in the poorest households, people vary their meals when they can. They are not just heating water, they are frying, 'bringing to the boil', and simmering. Each of these requires a different intensity of burn in biomass. Reduction of rate of burn in biomass stoves cannot be achieved instantaneously. Modern eco stoves with forced gasification can indeed be 'turned down' but reducing the rate of burn to simmer food, for example, was traditionally done by pulling sticks out. Given the lack of control of traditional stoves, people tend to take their pot off the stove to prevent it from burning.

With modern fuels such as electricity or LPG, the consumer is given a more precise control over the processes of cooking. This results in a lower overall consumption of energy for cooking a meal, and modern fuels should best be discussed in terms of useful energy required to cook a meal, not as conversion efficiencies of the stoves.

One of the few reports (and in our opinion a much neglected seminal piece of work) that compared fuel consumption under real cooking conditions is Cowan 2008[viii] Working in an informal housing community in South Africa, Cowan and his team cooked real meals and held public 'cooking trials' in order to raise awareness of the relative costs of fuels available. They undertook various types of cooking, ranging from a rice based meal, to longer term cooking of beef stews and even tripe. Biomass per se was not used by the community, and the comparison was between ethanol gel, LPGas, paraffin and (grid) electricity. As the graphs from Figure 4 show, electricity outperformed the other fuels by a considerable margin. One needs to note that at that time (2008) electricity was priced at approximately 6 cents a kWh, and therefore particularly cheap. South Africa has a 'free basic electricity' subsidy and this was discounted out of the calculation on the assumption that it was used for lighting.

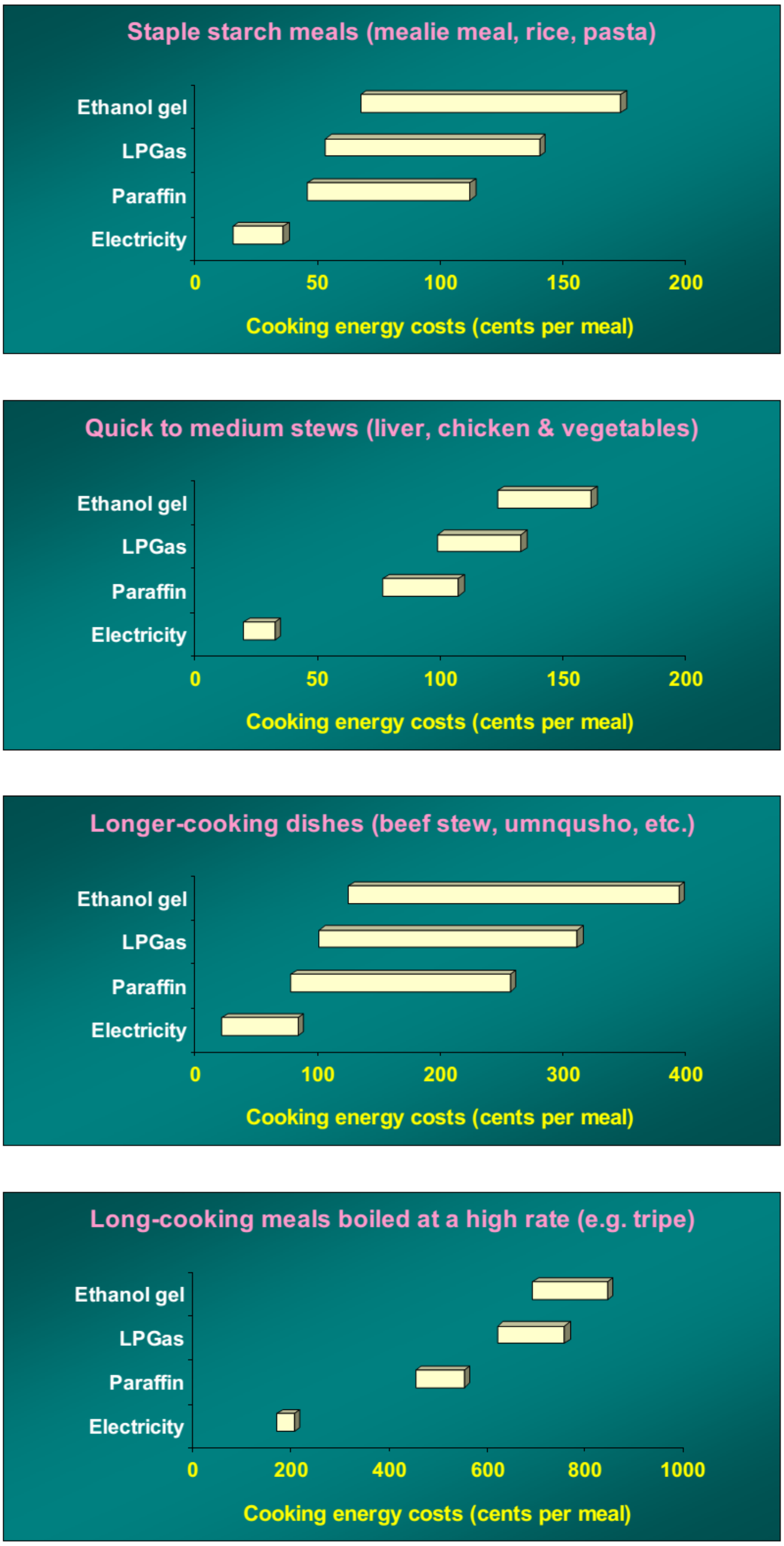

Figure 4 Energy costs for meals from Cowan 2008

However, more important to the current proposition is not so much the cost comparison in South Africa in 2008, but the energy consumed to cook the meal. A medium stew with chicken consumed 0.47kWh of electricity (0.57kWh ethanol gel, 0.74kWh LPG, 0.87kWh Paraffin). Cowan 2008

0.47kWh is 1.7MJ of energy. “The World Energy Council (1999) found that daily cooking energy consumption per capita varied from 11.5 to 49 MJ, based on field measurements. Despite a wide range of locations and conditions, the range of consumption is quite small. In households where modern cooking energy sources and equipment are used, and the preparation of partially cooked food is common, specific fuel consumption is found to be in the region of 2 to 3 MJ/capita/day.” Balmer 2007[ix]

This figure includes lighting, space heating and heating washing water. When we turn our attention back to cooking alone the required figure drops to around 0.4MJ per person per day (Own research 2015). Our research considered the theoretical per capita energy input to cook 40 different African meals (with savings when cooked as a family) (see Figure 5). While the expected range is there, the majority of meals are below 0.1kWh per person (approx. 0.4 MJ/person).

How many meals? Most surveys suggest that most resource poor African households have two meals. In particular GACC Kenya scan and GACC Tanzania scan.

So where people have adapted their cooking patterns to modern energy, the daily energy requirement for a four person family is of the order 1kWh of useful cooking energy:

2 meals * 4 persons * 0.1kWh = 0.8kWh

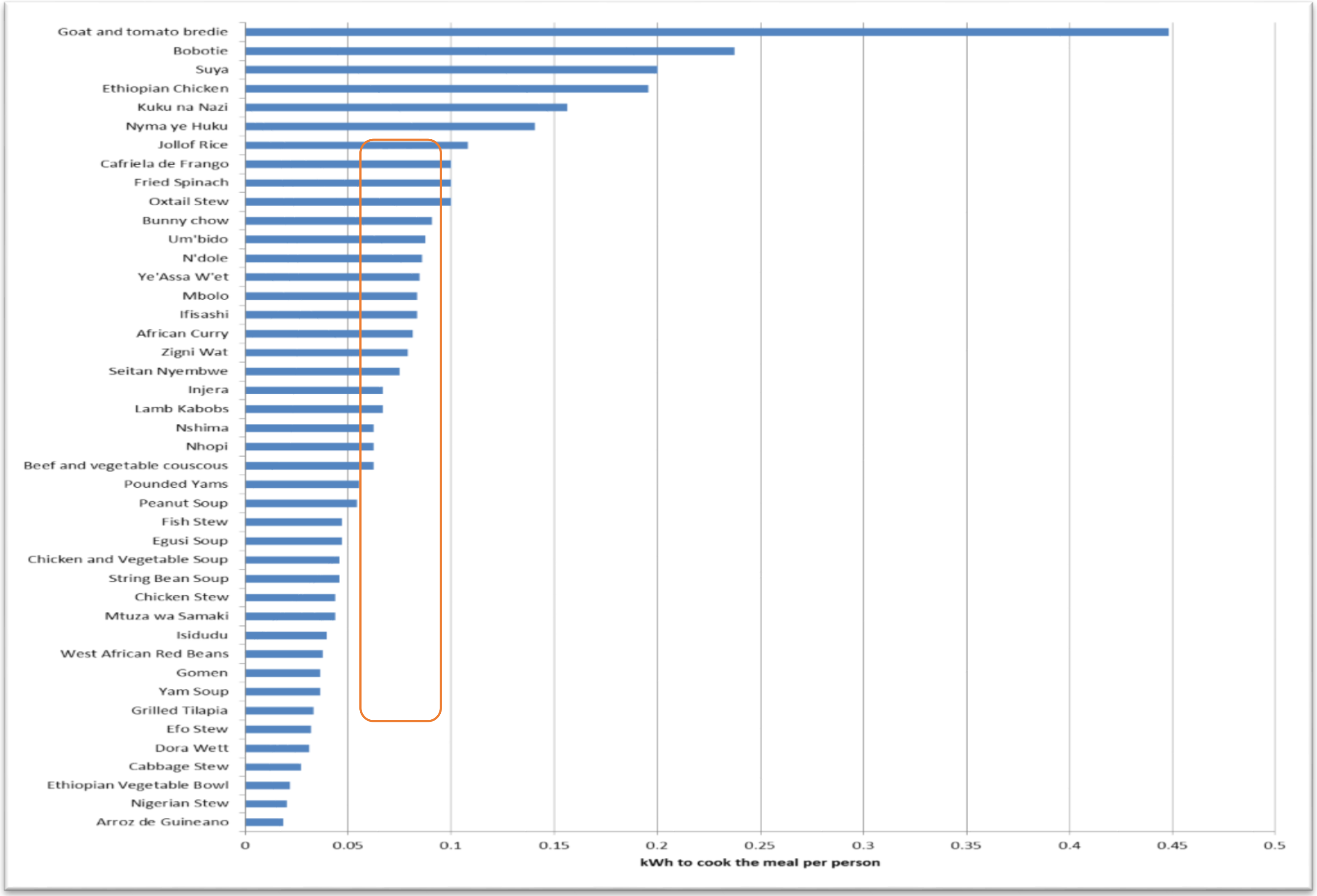

Figure 5 Energy consumed in making meals. Research on Cooking processes, Batchelor 2015.

4 Notes

In our market studies we have determined that some improved charcoal stoves are supplemented with use of the old three stone fire, because the improved stove does not give enough space heating. We expect that on cold days people revert to biomass use for space heating.

The literature talks about heating water as a basic need of the family. No studies have been found as to whether resource poor households actually heat water to wash. Our survey in Accra indicated that they do not, but this is an energy need that may need addressing, and needs specific market surveys.

Households host their family and friends for meals. We expect that on the days when larger meals are being cooked, the family will revert to a biomass stove.

5 Annex Details from Cowan 2008

Prices of fuels

Fuel	**Representative fuel prices (approx.) for domestic consumers in Imizamo Yethu**		
	Early 2006	*Mid 2008*	
Paraffin	R5 to R6 / litre	R10 to R15 / litre	
LPGas	R10 to R15 /kg	R20 to R25 / kg	
Candles	R6 to R8 / packet of six	R12 to R16 / packet	
Ethanol gel	R8 to R10 / litre	R10 to R15 / litre	
Electricity	R0.40 to R0.50 / kWh	R0.42 to R0.65 / kWh	Lower values include FBE[16]
Wood	not ascertained		
Approx R:€	8.5	12	

Availability and prices of cooking appliances

	Approx. price range	**Available from:**	*Notes*
1-plate stoves			
Paraffin	R70 to R140+	Some supermarkets, hardware stores, general dealers	*(i)*
LPGas	R400 (incl. cylinder)	Some supermarkets, hardware stores, etc.	
	R100 (excl. cylinder)	Supermarkets, hardware stores	
2-plate stoves			
Electric	R120 to R200	Most large supermarkets and similar shops	
Paraffin	not common		*(ii)*
LPGas	R500+ (incl. cylinder)	Some large supermarkets, hardware stores	
	R200 – R350 (excl. cylinder)	Some large supermarkets, hardware stores, etc.	*(iii)*
Electric kettles	R90 to R130		

(i) Mealie meal

- The cooking method (in this typical example): *Water is brought to the boil, mealie meal added, and simmered and stirred in an open pot until ready. When ready it is kept on a low heat until served.*
- Quantities cooked for four people are taken as: *0.5 kg mealie meal, with 1.8 kg water.*
- Additional ingredients considered: *100 to 200 mg oil or margarine.*

Fuel type	**Total cooking time (est.)**	**Energy consumed for cooking this meal**		**Typical costs of the food ingredients (R)**		**Cooking energy costs as a % of food costs**	
	(minutes)	kWh used	R spent	Main ingredients	All ingredients	% of main ingredients	% of all ingredients
Electricity	41	0.45	**R0.27**	3	5	9%	**5%**
Paraffin	44	0.84	**R0.93**	3	5	31%	**19%**
LPGas	34	0.79	**R1.26**	3	5	42%	**25%**
Ethanol gel	44	0.57	**R1.44**	3	5	48%	**29%**

Imizamo Yethu / S.Africa, 2008 circumstances & prices. The energy estimations are approximate, e.g. to within about ± 15%.

(ii) Boiled Rice

- The cooking method (in this typical example): *The rice and water are brought to the boil rapidly, then simmered in a closed pot for another 20 minutes, at lowest heating power.*
- Quantities cooked for four people are taken as: *0.35 kg dry rice, with 1 kg water.*
- Additional ingredients considered: *None (just salt).*

Fuel type	**Total cooking time (est.)**	**Energy consumed for cooking this meal**		**Typical costs of the food ingredients (R)**		**Cooking energy costs as a % of food costs**	
	(minutes)	kWh used	R spent	Main ingredients	All ingredients	% of main ingredients	% of all ingredients
Electricity	30	0.24	**R0.15**	5.25	5.25	3%	**3%**
Paraffin	31	0.45	**R0.49**	5.25	5.25	9%	**9%**
LPGas	26	0.35	**R0.57**	5.25	5.25	11%	**11%**
Ethanol gel	31	0.29	**R0.73**	5.25	5.25	14%	**14%**

Imizamo Yethu / S.Africa, 2008 circumstances & prices. The energy estimations are approximate, e.g. to within about ± 15%.

(ii) Medium-length meat stews (e.g. chicken and vegetable stew)

- The cooking method (in this typical example): *Oil is pre-heated in a stewing pot. Pieces of chicken are browned in the hot oil. Some flavouring vegetables and spices may be added at this stage, or later. The chicken is covered with water and stewed until tender, while substantial vegetables like carrots and potatoes are added in time to be soft when the chicken is ready. The stewing can be carried out at a low heat setting, but this may need to be raised to a medium heat setting when vegetables are added.*
- Quantities cooked for four people are taken as: *1.2 kg chicken pieces and vegetables, together. 1.5 kg water.*

• Additional ingredients considered: *Oil, flavouring vegetables (e.g. tomatoes, onions), spices and stock cubes, substantive vegetables (e.g. carrots, potatoes).*

Fuel type	**Total cooking time (est.)**	**Energy consumed for cooking this meal**		**Typical costs of the food ingredients (R)**		**Cooking energy costs as a % of food costs**	
	(minutes)	kWh used	R spent	Main ingredient (meat)	All ingredients	% of main ingredients	% of all ingredients
Electricity	48	0.47	**R0.28**	23	30	1%	**<1%**
Paraffin	51	0.87	**R0.96**	23	30	4%	**3%**
LPGas	41	0.74	**R1.19**	23	30	5%	**4%**
Ethanol gel	51	0.57	**R1.45**	23	30	6%	**5%**

Imizamo Yethu / S.Africa, 2008 circumstances & prices. The energy estimations are approximate, e.g. to within about ± 15%.

(iii) Longer-cooking meat stews (e.g. beef/mutton stew)

• The cooking method (in this typical example): *Oil is pre-heated in a stew pot. The pieces of meat are added and browned, over a high heat. Flavouring vegetables (e.g. onions) might be added at this stage, or later. This, and the combination of maximum stove power and quantity of food, can affect the browning time required. The browned meat is covered with water, possibly with further flavouring vegetables such as tomatoes, and stewed at a low heat for about 90 minutes. About 30 minutes before the end, substantial vegetables such as potatoes and carrots are added (with the heat increased, if necessary). Seasoning is adjusted towards the end of the cooking period.*

• Quantities cooked for four people are taken as: *1 kg meat, 0.5 kg vegetables, 1.5 litres water.*

• Additional ingredients considered: *In addition to the meat – oil, vegetables and flavourants (such as stock cubes / spice mixes).*

Fuel type	**Total cooking time (est.)**	**Energy consumed for cooking this meal**		**Typical costs of the food ingredients (R)**		**Cooking energy costs as a % of food costs**	
	(minutes)	kWh used	R spent	Main ingredient (meat)	All ingredients	% of main ingredients	% of all ingredients
Electricity	132	1.11	**R0.67**	40	48	2%	**1%**
Paraffin	140	2.09	**R2.30**	40	48	6%	**5%**
LPGas	120	1.75	**R2.80**	40	48	7%	**6%**
Ethanol gel	150	1.40	**R3.55**	40	48	9%	**7%**

Imizamo Yethu / S.Africa, 2008 circumstances & prices. The energy estimations are approximate, e.g. to within about ± 15%.

(iv) <u>Longer-cooking dried vegetable dishes (e.g. samp and beans)</u>

- The cooking method (in this typical example): *The dried ingredients, i.e. samp (chipped maize) and beans (e.g. sugar beans), are soaked overnight. If not, this can increase the required cooking times by about 30 minutes. They are then brought to the boil in sufficient water, and simmered for another 90 minutes or more, until tender. Vegetables and flavourants may be added.*
- Quantities cooked for four people are taken as: *0.7 kg samp and beans, 3 litres water.*
- Additional ingredients considered: *oil, vegetables and flavourants (such as stock cubes / spice mixes).*

Fuel type	**Total cooking time (est.)**	**Energy consumed for cooking this meal**		**Typical costs of the food ingredients (R)**		**Cooking energy costs as a % of food costs**	
	(minutes)	kWh used	R spent	Main ingredients	All ingredients	% of main ingredients	% of all ingredients
Electricity	118	0.84	**R0.51**	8.5	13	6%	**4%**
Paraffin	123	1.57	**R1.72**	8.5	13	20%	**13%**
LPGas	106	1.29	**R2.07**	8.5	13	24%	**16%**
Ethanol gel	123	0.99	**R2.52**	8.5	13	30%	**19%**

Imizamo Yethu / S.Africa, 2008 circumstances & prices. The energy estimations are approximate, e.g. to within about ± 15%.

Compared with the amount of power desired from a stove in order to boil a pot efficiently, the amount of power required for efficient simmering can be much less. Using the example of a common electric hotplate, its maximum power might be 1000 Watts, and this would be the best setting for boiling water, but when it comes to the simmering phase, the stove could be turned down to 200 Watts or less for optimum efficiency. Usually, families boil and simmer meals on the same stove.

Efficient boiling requires quite high power, while efficient simmering requires quite low and controllable stove power. Hence, an important measure of the practical efficiency of a cooking stove is its "turn-down ratio". This is the ratio between its maximum power and its controllable low power settings, and should preferably be at least 5:1.

"The meal comprises a sheep's head, and feet, which are boiled for approximately three hours. The young man who was monitored while cooking this meal uses a portable gas stove for this purpose (although he has electricity in his home, and does his regular cooking on electricity). He believes that gas is more economical than electricity for such long cooking periods. However, according to tests and calculations, using gas for this purpose is considerably more expensive than electricity, at current prices, partly due to the high cost of LPG as at present, but made worse because the gas stove he uses is difficult to turn down to a reliable simmering heat. As a result, the pot carries on boiling for three hours. It has an ill-fitting lid, and loses so much heat through steaming that he has to add more cold water on a regular basis. He soaks up the boiled-over water with newspapers underneath the stove, emphasising the wasted heat losses." (Cowan 2008)

This anecdotal info relating to institutional cooking does not seem relevant

In public cooking competitions, during the APPLES project, a background activity was to cook meals for about 80 people on each occasion (for members of the community audience), while the competing cooks were each preparing typical dishes for a smaller household-sized group of people e.g. four to six. The communal cooking for the larger audience made use of electric and gas stoves, especially the highest-power gas stoves, the highest power electric stoves available, and mixed combinations, for example

- x placing large pots across two plates of an electric two-plate stove for faster heating (a bit faster, but very inefficient, as the red-hot hotplates were only partly covered by the pot)
- x using the fastest gas stoves to bring water to boiling point, then moving the pots to slower electric stoves. A wood-fire was also used, but only as a side-event in this situation (for braaing / grilling some of the meat).

Economical cuts of stewing meat may not be suitable for braaing, as they would be tough; and there is a disincentive to placing aluminium pots on a wood fire, as it is difficult to clean away the carbon deposits afterwards.

---

[i] R Bacon, S Bhattacharya, M Kojima 2010 "Expenditure of Low-Income – Based on Households on Energy Evidence from Africa and Asia". World Bank http://siteresources.worldbank.org/EXTOGMC/Resources/336929-1266963339030/eifd16_expenditure.pdf

[ii] Prüss-Üstün and C. Corvalán 2006 "Preventing disease through healthy environments: Towards an estimate of the environmental burden of disease" WHO http://www.who.int/quantifying_ehimpacts/publications/preventingdisease5.pdf

[iii] ESMAP Technical Report 007/15 "THE STATE OF THE GLOBAL CLEAN AND IMPROVED COOKING SECTOR" ESMAP & Global Alliance for Clean Cookstoves. May 2015 Note - Disability Adjusted Life Years – taking into account lost productivity and quality of life associated with a disease.
https://openknowledge.worldbank.org/bitstream/handle/10986/21878/96499.pdf?sequence=1

[iv] ibid WHO above

[v] UNEP website
http://www.unep.org/climatechange/mitigation/Bioenergy/Issues/TraditionaluseofBiomass/tabid/29473/Default.aspx

[vi] IEA, World Energy Outlook Special Report 2014 http://www.worldenergyoutlook.org/resources/energydevelopment/

[vii] ibid ESMAP 2015

[viii] Cowan 2008 Alleviation of Poverty through the Provision of Local Energy Services APPLES (Project no. EIE-04-168) Project Deliverable No. 17: Identification and demonstration of selected energy best practices for low-income urban communities in South Africa

[ix] Balmer, M. 2007. Energy Poverty and cooking energy requirements: The forgotten issue in South African energy policy? Journal of Energy in Southern Africa, Vol, 18, No.3