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Household Use of Bottled Gas for Cooking

Evidence from Sub-Saharan Africa

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Abstract

Analysis of household energy use has tended to focus on primary energy sources for cooking, lighting, and heating. However, even those using clean primary energy sources are not necessarily free from household air pollution and the burden of biomass collection because of commonly practiced fuel stacking. This paper examines household energy use in 24 Sub-Saharan African countries with a focus on bottled cooking gas, which is expected to play a pivotal role in the attainment of universal access to clean household energy by 2030. The share of people using clean energy (electricity and gas) as the primary source exceeded half only in five countries, with liquefied petroleum gas dominating in three and electricity in two. As income rose, households shifted away from wood in every country, to clean energy in most countries and to charcoal in some. Of the 12 countries (nationally or in urban areas) in which at least one-fifth of the population used liquefied petroleum gas as their primary cooking fuel, more than three-fifths of primary liquefied petroleum gas users had abandoned polluting fuels in five countries. Within per capita expenditure quintiles, households who had abandoned all polluting fuels were consistently smaller than those who continued to use polluting fuels, mainly charcoal or kerosene, perhaps pointing to the ease of cooking for small families exclusively with liquefied petroleum gas and electricity. However, liquefied petroleum gas–using households in the top expenditure quintile who had not abandoned polluting fuels were on average smaller than those in the fourth quintile who had abandoned polluting fuels. These findings point to reasons for fuel stacking that seem to go beyond the question of affordability.

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Household Use of Bottled Gas for Cooking: Evidence from Sub-Saharan Africa*

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Background and Context

Many governments have encouraged the use of liquefied petroleum gas (LPG) for cooking for several decades. Aside from creating an enabling regulatory framework to attract investment and encourage LPG supply to the domestic market, many governments have provided additional support. The latter has taken several forms, the most prevalent of which has been a universal price subsidy for household use of LPG. Because LPG is also used by commercial establishments, price subsidies are typically—but not always—earmarked for LPG sold in small cylinders, containing up to about 15 kilograms (kg) of LPG. Some governments—such as in Ghana and India—have also subsidized the initial acquisition of LPG cylinders, LPG stoves, or both. Examples of other forms of financial support by governments include the engagement by the Thai government with the state-owned oil company to construct six large LPG storage and terminal facilities nationwide (Ekouevi and Tuntivate 2012) and creation in 1998 of the Ghana Cylinder Manufacturing Company by the government to promote substitution of LPG for charcoal and firewood to stop degradation, deforestation, and desertification.

Universal fuel price subsidies in developing countries are regressive (Arze del Granado, Coady, and Gillingham 2012) and those for LPG are especially so because unsubsidized LPG is relatively expensive compared to the income of the poor. In recognition of the regressive nature of universal price subsidies, several governments have moved away from price subsidies to conditional cash transfers—whereby cash transfers are made to those who purchase LPG—or targeted unconditional cash transfers. Cash transfers have been facilitated by advances in mobile and other information technologies, and in turn have enabled the LPG market to move to market-based pricing, thereby reducing economic distortions and leakages. Replacing universal price subsidies with cash transfers has helped slash diversion, black marketing, and subsidy burdens on governments, LPG suppliers, or both. Implementation has encountered a range of teething problems but governments have tackled them and continue to improve the cash transfer delivery mechanism (Kojima 2021a).

In the 1980s and the 1990s, an important driver of support for LPG was the concern to stem deforestation from growing use of wood fuel (fuelwood and charcoal). To that end, governments supported sustainable forest management and in parallel made efforts to reduce consumption of wood fuel by improving the efficiency of wood fuel stoves and shift household use of energy for cooking to LPG.

A study published in 2003 reviewing data over the previous decade concluded that data did not support the earlier concern that wood fuel demand had been outpacing sustainable supply at so large a scale as to become a major cause of deforestation (Arnold et al. 2013). This revised assessment has since been supported by annual publications on forestry by the Food and Agriculture Organization and the United Nations Environment Programme. According to the 2020 issue of *The State of the World's Forests* (FAO and UNEP 2020), nearly three-quarters of deforestation and the associated loss of forest biodiversity globally are from agricultural expansion, more than half of which is mainly cattle ranching and cultivation of soybean and oil palm with subsistence agriculture comprising the rest. Wood fuel consumption has declined or remained steady over time in most regions, but with the exception of Sub-Saharan Africa where it has continued to increase.

Arnold et al. also concluded that the rapid rise in charcoal production—which requires large quantities of wood to manufacture—warranted further investigation, especially where urban demand for charcoal was rising against the backdrop of the global population migration from rural to urban areas. The statistics from the Food and Agriculture Organization[3] show that global charcoal production doubled from 26 million tonnes in 1980 to 54 million tonnes in 2020. During the intervening four decades, Africa's share increased steadily, from 44 percent in the first decade (1980–1990) to 53 percent in the second decade (1990–2000), 57 percent in the third decade (2000–2010), and 63 percent in the decade ending in 2020. With wood fuel representing more than 90 percent of all wood harvested, Africa lost 3.94 million hectares per year of forest area between 2010 and 2020, the highest net loss of any region, followed by 2.60 million hectares per year in South America. Africa is the only region of the world where the total forest area decreased steadily in three successive decades from 1990 to 2020 (FAO and UNEP 2020).

Household use of wood fuels has far-reaching effects beyond cooking and heating. An estimated 880 million people worldwide spend part of their time collecting fuelwood or producing charcoal, many of them women. More than 40 million people, or 1.2 percent of the global workforce, are engaged in commercial fuelwood and charcoal activities (FAO and UNEP 2020). To the extent that those collecting fuelwood for own consumption can free up time, clean household energy provides an additional benefit. But to the extent that charcoal production and firewood gathering for sale is bringing income to 40 million people, the loss of revenue would initially present a socioeconomic problem. Such activities could even provide social stability. A study collecting primary data in 2011 in Sierra Leone found that 63 of 64 charcoal-producing villages visited during the data collection had not been involved in charcoal production prior to the civil war. One charcoal trading village consisted entirely of ex-combatants who had turned to cooperative charcoal production as their exclusive source of income (Munro, van der Horst, and Healy 2017).

As the sense of urgency about biomass use driving global deforestation has abated, the last two decades have seen a growing recognition of the high human cost of air pollution from household use of fuels emitting harmful pollutants. The World Health Organization in 2018 estimated, based on updated data from 2016, that 3.8 million a year died prematurely from illnesses attributable to elevated concentrations of $PM_{2.5}$—particulate matter with an aerodynamic diameter of 2.5 microns or less—caused by emissions from household use of solid fuels and kerosene for cooking.[4] An updated estimation for 2019 shows that the number of premature deaths from household air pollution had declined to 2.3 million (HEI 2020), but there were large regional differences. South and East Asia had made considerable progress in reducing the number of people exposed to household air pollution, driven by China and India, which had the largest reduction in the total number of people exposed between 2010 and 2019. By contrast, despite the declining *percentage* of the population exposed, several countries in Sub-Saharan Africa with rapidly increasing population saw an increase in the total *number* of people exposed. Globally, in the 17 countries with more than 50 million people and at least 10 percent of the population living in households with solid fuel use, five countries saw a net increase in the number of people exposed to household air pollution in the two decades, all of them in Sub-Saharan Africa.

In light of the foregoing and additional concerns about the toll—especially on women and children—of the drudgery of fuel collection and additional labor and time associated with cooking with solid fuels using traditional stoves, the United Nations General Assembly in 2015 adopted the resolution,[5] "Transforming our world: the 2030 Agenda for Sustainable Development," with 17 Sustainable

[3] http://www.fao.org/faostat/en/#data/FO.
[4] https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health.
[5] https://undocs.org/en/A/RES/70/1.

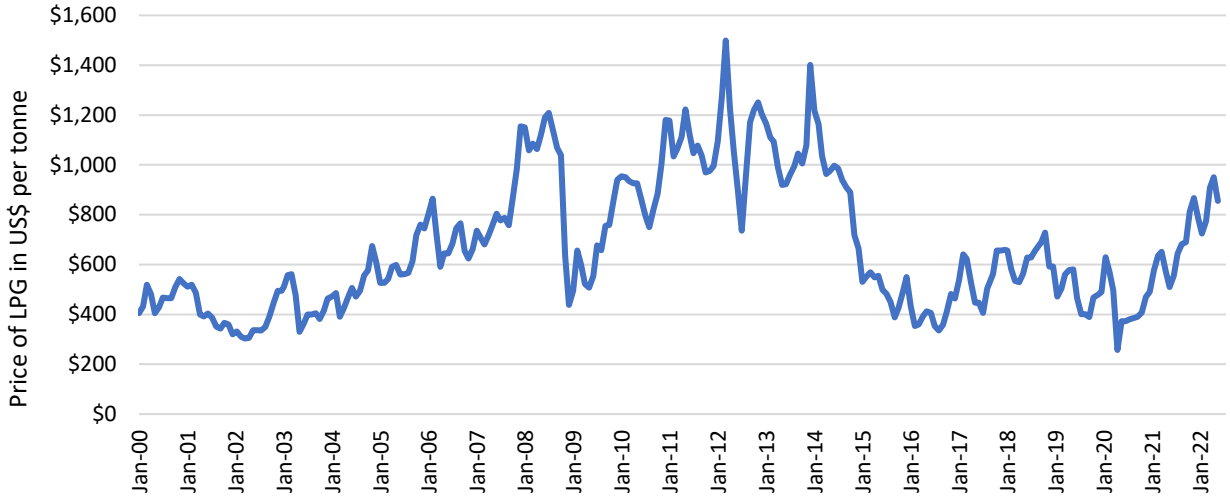
Development Goals (SDGs), of which SDG 7 is about "access to affordable, reliable, sustainable and modern energy for all" and sub-goal SDG 7.1 aims, "by 2030, [to] ensure universal access to affordable, reliable and modern energy services." SDG 7.1 in turn comprises two components, (1) access to electricity and (2) primary reliance on clean fuels and technology.

The global trend over the last decade regarding access to clean cooking fuels and technologies suggests that the 2030 target will be missed. A group of international agencies has been estimating the number and share of people living in households who use clean fuels and technologies—comprising electric, LPG, natural gas, biogas, solar, and alcohol-fuel stoves—as their primary sources of energy for cooking. The last year for which the data are available is 2019, when only about 66 percent of the world population was estimated to be using clean fuels and technologies as their primary means of cooking, up from 57 percent in 2010 (IEA et al. 2021).

At the present rate of progress, nearly one-third of the global population would still not have access to clean cooking by 2030. The COVID-19 pandemic has slowed down the rate of progress toward universal access further. Although international LPG prices had collapsed initially, they have since rebounded, while the economic consequences of lock-downs and other measures have depressed the income of many poor households, forcing them to abandon commercial fuels in favor of freely collected solid fuels. Nor has the rate of progress toward clean cooking been evenly distributed across different regions. Sub-Saharan Africa is the only region where the population growth has outstripped the increase in the number of people gaining access to clean cooking. For example, the population in Sub-Saharan Africa increased by 27 million a year between 2015 and 2019, while the number of people with access to clean cooking increased by only 10 million a year during the same period.

Arguably, the two most important drivers of energy choice are income and prices. In this regard, the high volatility of international LPG prices since the early 2000s has further exacerbated the difficulties of cooking with LPG. Figure 1 shows that the equivalent of free-on-board prices—which form the basis for retail prices—have varied from US$260 per tonne to US$1,500 per tonne over the past decade. The costs of shipping, storage, bottling, transportation, and retail will add US$300 per tonne or more. Using 5 percent of the household income as the upper bound on affordable expenditure on cooking as suggested by the multi-tier framework for access (Bhatia and Angelou 2015), the minimal monthly total household income needed for regular use of LPG for cooking can be calculated. Regular use for cooking would require at least 10 kilograms (kg) of LPG per month and preferably 15 kg or more (Kojima 2011). Since 2010, households that could have consistently purchased 12.5 kg of LPG every month would have needed annual household income of at least US$5,400, a level high enough to exclude not only the poor but also lower-middle-income families in many developing countries.

Figure 1 History of LPG prices in the Arab Gulf in 2022 U.S. dollars



Source: RIM LPG Intelligence Daily.
Note: Prices are the average of Saudi Aramco contract prices for propane and butane.

The harm caused by the inadequate rate of progress is even greater than what the statistics about primary cooking energy suggest. This is because the metric defined for the purpose of measuring progress for SDG 7.1, "proportion of population with primary reliance on clean fuels and technology," captures only two of several household activities—namely cooking and lighting but to date heating water, space heating, preparation of animal feed, and other activities have been excluded because such data are seldom collected systematically in national household surveys—and, even if all activities were to be captured, the metric still fails to capture important uses of polluting fuels:

- Information on primary reliance is usually obtained from national household surveys, almost all of which ask about the primary sources of energy for lighting and cooking. Many households use multiple fuels and technologies—referred to in the literature as fuel stacking or stove stacking—and it is unclear what criteria are used to identify primary sources. Is primary use defined by the number of hours each fuel or stove is used, the number of meals cooked, or the number of main dishes made? How do households account for the seasonality of the availability of different fuels, making them dependent on different fuels at different times of the year?
- These surveys offer wood, charcoal, agricultural residues, dung, and coal as solid fuel options to choose from without specifying the stove type. In particular, survey questionnaires to date have not asked about advanced-combustion biomass stoves. As such, households purchasing densified wood pellets and using advanced-combustion gasifier pellet stoves—admittedly very small in number at this time but could grow in the coming years—would be lumped together with households burning twigs and branches over three-stone-fire stoves.

Fuel and stove stacking substantially diminishes the benefits of primary reliance on clean fuels and technology. Primary reliance on clean cooking fuels and technology does not signal abandonment of polluting cooking practices, let alone polluting household energy use. A 2000 publication studying household use of fuels in rural Mexico was among the first to challenge the previously held so-called energy ladder theory (Masera, Saatkamp, and Kammen 2000). The bottom of the ladder comprises wood, agricultural residues, dung, and other potentially free but polluting fuels. As income rises, households move up the ladder to commercial but still polluting fuels such as charcoal, kerosene, and coal. At the top of the ladder is modern clean energy used exclusively by those in high-income countries: electricity,

natural gas, and LPG. Households were believed to move up the energy ladder with rising income, abandoning energy in the lower rung of the ladder as doing so became affordable. This linear fuel switching model would make it possible to link primary energy use directly to the benefits of modern clean energy, especially better health outcome. Instead, the authors found that the dynamics of household fuel use were not so linear or unidirectional. Households were found to move to multiple-fuel cooking with rising income in a bidirectional process—meaning that separate, coexisting factors simultaneously pushed households away from biomass and pulled them back. Even when households had been using LPG for many years, they rarely abandoned fuelwood use. Fuelwood savings from using LPG ranged from 35 percent on average in one village to as little as zero percent in another. Expenditures on fuelwood were higher in some cases in households using both fuelwood and LPG than in fuelwood-only households. The authors concluded that economic development, which would enable use of technologies higher on the energy ladder, did not correlate with pollution reduction.

Fuel stacking is especially problematic for health outcomes. Johnson and Chiang (2015) concluded from running a model that that using a three-stone fire for a few minutes a day would elevate $PM_{2.5}$ concentrations above any of the targets set by the World Health Organization. Traditional charcoal stoves could be used longer but still to less than 10 minutes a day.

The International Energy Agency (IEA) projects that, given current trends, 2.1 billion people will still lack access to clean cooking in 2030. The three most likely and widely available options for clean cooking are electricity, natural gas, and LPG. Across the world natural gas is potentially available primarily in urban areas; in Sub-Saharan Africa, which has the largest access gap, natural gas is not available even to urban households. The IEA hence estimates that in the scenario in which only policies already announced are implemented, about two-thirds of those gaining access will be adopting LPG as the primary cooking fuel. Although LPG is a fossil fuel, because its combustion largely does not produce black carbon and other emissions with high global warming potential, LPG would play an important role as a household fuel even in the scenario achieving net-zero greenhouse gas emissions by 2050. In the latter scenario, more than one-third of those gaining access (under universal access by 2030) would do so by adopting LPG, requiring an annual investment of US$1.2 billion in LPG infrastructure alone (IEA 2021).

There is evidence that subsidies have boosted household use of LPG and led to its adoption as the primary cooking fuel among some better-off households, but many poor households have used subsidies to start using LPG, only to discontinue its use later. Even among those who continue to use LPG, traditional use of solid biomass continues. There are numerous reasons for not abandoning it even as households cite gas or electricity as their primary sources of energy for cooking. Aside from higher costs of exclusive use of modern energy, occasional or frequent shortages of electricity and gas, fuel price volatility (especially LPG, although natural gas prices can also rise markedly), and cooking preferences are among other reasons (Kojima 2021a and 2021b). Of these, households have no control over a lack of reliable supply. Many developing countries suffer from unreliable electricity and some experience frequent power outages lasting hours. A lack of LPG, either altogether or occasional, is closely correlated with a lack of sufficient demand, creating a vicious cycle. If the supply is unreliable or non-existent, households do not adopt LPG and use it regularly, limiting consumption. Because demand is low, marketers cannot achieve the requisite economies of scale to develop commercially viable markets for LPG and choose not to devote efforts to supplying these new markets, perpetuating the lack of supply reliability.

There is only a limited literature documenting *abandonment* of polluting fuels and stoves by households. For example, there is a large literature on household use of LPG based on data from national household surveys or other surveys to study primary household energy sources, including adoption of LPG as the

primary cooking fuel. By contrast, there is a handful of publications examining exclusive users of LPG. Mani et al. (2020) used panel data to examine shifting household fuel use patterns for cooking three years apart in 2015 and 2018. Of the exclusive users of LPG in 2015, one-third had ceased to be exclusive users by 2018, with 10 percent having become minority users. More encouragingly, 46 percent of primary users and 23 percent of minority users in 2015 had become exclusive users by 2018 and the total number of exclusive users had doubled during the intervening years. Thoday et al. (2018) examined the impact of Indonesia's kerosene-to-LPG conversion subsidy program on abandonment of wood use. Williams et al. (2000) used stove monitors to see if removing all financial barriers to regular use of LPG would see households cook exclusively with LPG in Puno, Peru, and found that fewer than half of the participating households in the study seemed to have done so. Asante et al. (2018) carried out the first systematic evaluation of the Rural LPG Promotion Program in Ghana and did not find exclusive users even in the initial stage of evaluation. After 18 months, only 8 percent of the study participants were still using LPG. In terms of national statistics being made available, Peru's Instituto Nacional de Estadística e Informática (INEI, National Institute of Statistics and Informatics) published a breakdown of exclusive and non-exclusive users of LPG, natural gas, and electricity by the poverty status every year between 2007 and 2017 (INEI 2018).

This study adds to this limited literature by focusing on LPG as a cooking fuel and abandonment of polluting fuels following adoption of LPG. The study uses national household expenditure surveys in Sub-Saharan Africa to gain a better understanding of patterns of household energy use for cooking with a view to refining government support to household use of LPG. In contrast to the Multiple Indicator Cluster Surveys (Kojima 2021c) or Demographic and Health Surveys,[6] which are valuable sources of information about primary cooking, lighting, and heating energy sources but contain no information about energy stacking, data from national household expenditure surveys enable not only calculation of how much households spent on commercial forms of energy but also assessment of whether households had abandoned use of polluting fuels. The study was confined to Sub-Saharan Africa, the region with the largest access gap and therefore the rate of abandonment of polluting fuels and technologies is presumably correspondingly the lowest. Examining the extent of abandonment and incremental costs of doing so could inform policy makers as they consider different forms of support for the purpose of achieving universal access to clean household energy.

Study Description

This study analyzed national household expenditure surveys conducted between 2014 and 2019 in 24 Sub-Saharan African countries. The names of the surveys, dates of data collection, and annual expenditures per capita expressed in 2022 U.S. dollars can be found in annex 1. The countries included those with very large price subsidies for LPG (Angola and Sudan in particular) and those with no price subsidies. LPG users were defined as those with non-zero expenditures on LPG. The questionnaire in Cameroon asked about the possession of LPG stoves and cylinders, and households with such possession were also considered to have been LPG users. Consistent with the definition provided by the World Health Organization, this paper considers electricity, LPG, biogas, solar cookers, and ethanol clean forms of energy—although questions about ethanol were asked only in Nigeria where only a handful of households in urban areas cited ethanol as their primary cooking fuel—and all other fuels are considered polluting, including charcoal and kerosene.

[6] https://dhsprogram.com/.

Total household expenditures are the same as those used to calculate the poverty rate in the countries and, where temporal and spatial deflators are available, adjusted accordingly. Annual expenditures per capita in 2022 U.S. dollars ranged from US$318 in Ethiopia to US$4,000 in Mauritius. Per capita expenditures were converted from the local currency to U.S. dollars using the official exchange rate and adjusted to 2022 U.S. dollars. As explained in annex 1, some governments maintained substantially over-valued exchange rates, making per capita expenditures much higher than those based on market-based rates. Because electricity prices are unaffected by spatial deflators and LPG prices are also unaffected in many countries, when they were used in calculations—such as comparing spending on LPG and electricity by various households—their values were not deflated. Expenditure shares were similarly calculated using un-deflated values.

Although national household expenditure surveys have the advantages mentioned in the previous section, there are limitations:

- For energy items, households are typically asked how much they had spent on a given item in the previous month or in the last 30 days or in a typical month, all of which are intended to calculate the average monthly household expenditure on the item. However, it is clear from the responses that many report how much they had paid for the last purchase or in the last month. As an illustration of the pitfalls of this approach, if a household refills an LPG cylinder every six weeks, depending on the timing of the survey, the respondent may report zero spending on LPG. A clear example of data inconsistencies arising from this type of problem is the Mexican household survey, in which the relatively large sizes of LPG cylinders and tanks commonly used in Mexico appear to result in many LPG-using households reporting zero expenditure in the previous month. For example, in the 2008 survey, 80 percent of households reported that LPG was their primary cooking fuel but only 60 percent had reported non-zero expenditures because they were asked to tell the enumerator how much they had spent on LPG in the previous month (Kojima, Bacon, and Zhou 2011). Conversely, a household that purchases LPG less frequently than once a month but happened to have had purchased LPG in the preceding month might report the full purchase amount, over-stating how much the household spends on LPG on average every month.
- Expenditures on consumed goods and services obtained free of charge, such as wood or dung gathered by households, are usually imputed "market" values but how systematically they are recorded and valued is unclear. In the extreme, in areas where firewood is virtually universally collected and there is no market for it, assigning a market value would be challenging. In addition, while households may recall how much they had spent purchasing wood in the last 30 days, those collecting wood would need to estimate the quantity, which would be multiplied by the proxy market price. Doing so accurately would be extremely challenging even under the best of circumstances.
- Apart from asking about primary sources of energy for cooking and lighting, questions about end-use are typically not asked. Even when primary sources are known, they may be used for other purposes. For example, if a household cites kerosene as the primary source of energy only for lighting, it does not follow that kerosene is never used for cooking. Particularly problematic are gasoline and diesel, which may be used as automotive fuels in vehicles or fuels in electricity generators, and if the latter, electricity so generated could be used for cooking. Unless their uses are distinguished in the survey questionnaire, which they are usually not, it is not possible to tell how they were used by households reporting non-zero expenditures on either of these fuels and hence they are included in Figure 4.

The procedure for aggregating consumption in each country was that followed to examine the poverty rate. Per capita expenditures were computed by dividing household expenditures by household size. Population weights were used to classify the entire population into five expenditure quintiles with the same number of people in each quintile. The bottom quintile, or quintile 1, had the lowest expenditure per capita and the top quintile, or quintile 5, had the highest expenditure per capita. Because the household size on average decreases with increasing wealth, the *number of households* increased with increasing quintile. The quintiles were further segregated into urban and rural. The lower quintiles had many more rural households while urban households tended to be in upper quintiles. In Mauritius, the publicly available survey data sets did not contain information on the split between urban and rural, and hence only national results are presented. Universal access is generally measured by population and not households, including for the purpose of tracking SDG 7, and hence the results in this paper related to access are expressed as percentages of people rather than households. Because household representatives answer questions about household use of energy, the phrase used is "people living in households citing [or using]" a specific form of energy.

For the purpose of computing the share of total household expenditures spent on different forms of energy, outliers—defined as those spending more than 30 percent of total expenditures on any form of energy—were excluded to avoid having them dominate the results. All surveys enabled calculations of total household expenditures, taken as a proxy for income to leading order, with the exception of the South African survey, which asked households to choose one of the 10 income brackets. As a result, expenditure quintiles could not be computed for South Africa. Outlier households were not excluded in all other calculations, such as the number of people citing different forms of primary energy for cooking or those who had abandoned the use of polluting fuels.

One challenge in interpreting the expenditures is that freely acquired goods—the largest proportion of which is food, especially in rural areas, but solid biomass may also be collected free of cash—are included, making total expenditures less representative of income for those households where a material fraction of total expenditures is imputed. Modern commercial energy requires cash outlays, and the ability to pay for LPG or electricity is a function of both income and the needs that are met through cash-free acquisition, making neither total household expenditures as calculated nor cash-only expenditures fully satisfactory for the purpose of assessing the ability to pay. Further, many households do not distinguish how a given good was acquired, especially different forms of energy, and hence calculating cash expenditures consistently across the countries surveyed was not possible.

This study classifies kerosene, wood, charcoal, coal, dung, agricultural residues, other solid fuels, and energy characterized as "other" in the survey questionnaire as polluting fuels. While wood may have included compressed pellets burned in advanced-combustion stoves (Kojima 2021b), such occurrences would have been extremely rare in Sub-Saharan Africa during the survey period and their exclusion would not have materially distorted the results. A household was considered to have had abandoned polluting fuels if the household did not name a polluting fuel as the primary cooking fuel and reported zero expenditures on all polluting fuels. Abandonment so measured signals abandonment of all polluting fuels by the household for all household activities and not just for cooking.

Abandonment of polluting fuels following LPG adoption was examined by confining the samples to those areas where there were enough households using LPG as their primary cooking fuel. Because the sample size varied from fewer than 4,000 in Eswatini and Niger to slightly more than 20,000 in three countries, the cut-off point of 20 percent was chosen as the selection criterion for examination of abandonment—intended to strike a balance between coverage (having enough countries for analysis) and significance (obtaining representative results)—and only those areas where 20 percent or more of the population cited

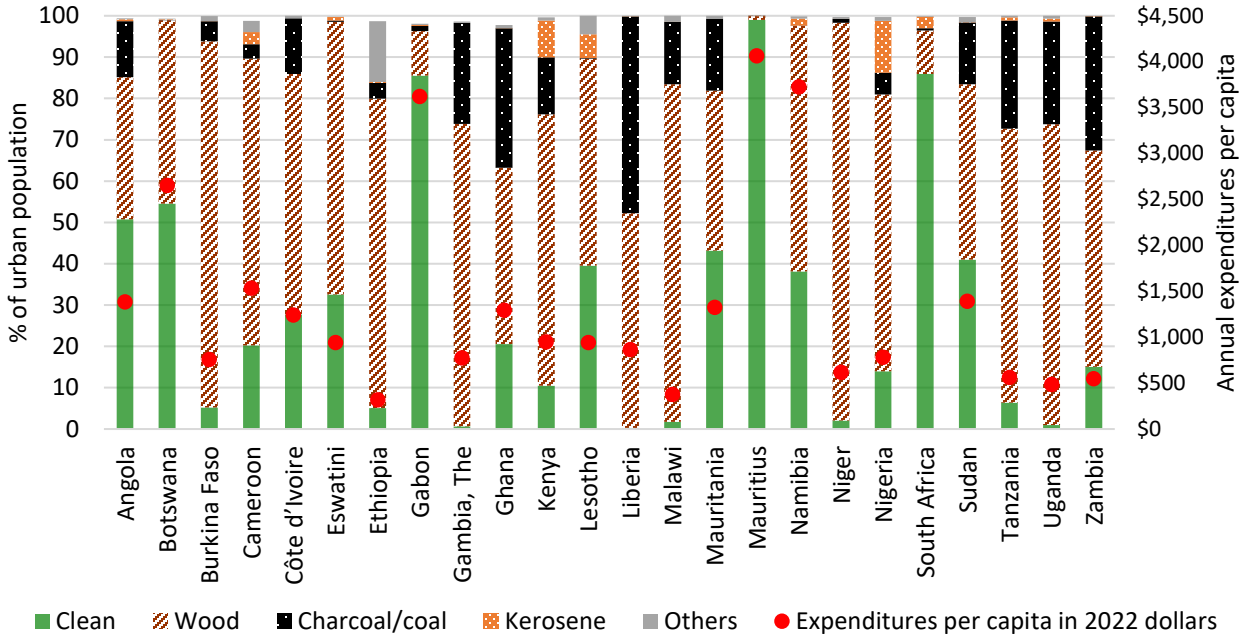
using LPG as the primary cooking fuel were retained for the analysis. If the 20 percent mark was exceeded nationally, the national data were used. Burkina Faso, Kenya, and Nigeria did not meet the 20 percent mark nationally but met it in urban areas, and hence in these three countries only urban households were analyzed. Although use of gasoline or diesel for back-up power generation is polluting, most household survey questionnaires did not distinguish between automotive and electricity-generation uses of these two fuels, and hence they were not included among the polluting household fuels.

LPG users are categorized into three types: (1) those who use LPG as the primary cooking fuel and have abandoned polluting fuels altogether; (2) those who use LPG as the primary cooking fuel and continue to use other fuels, including polluting fuels; and (3) those who use LPG but not as the primary cooking fuel. The households in the last category were identified by searching for those who reported non-zero expenditures on LPG and did not name it as the primary cooking fuel.

Patterns of Primary Household Energy Choice for Cooking

Comparison of primary energy sources for cooking showed significant differences from country to country. The share of people living in households citing clean sources of energy ranged from 99 percent in Mauritius to less than 1 percent in The Gambia, Liberia, and Uganda. Only five countries had more than half of the entire population living in households using clean cooking energy, whereas 16 countries had more than half using wood as the primary cooking fuel. When wood, charcoal, and coal were combined into a single category, the country count increased to 19 (Figure 2). There was a broad correlation between income (represented by national average annual expenditures per capita) and the share of people living in households citing clean energy as their primary sources for cooking.

Figure 2 Percentage of people living in households citing different primary energy sources for cooking and national annual expenditures per capita



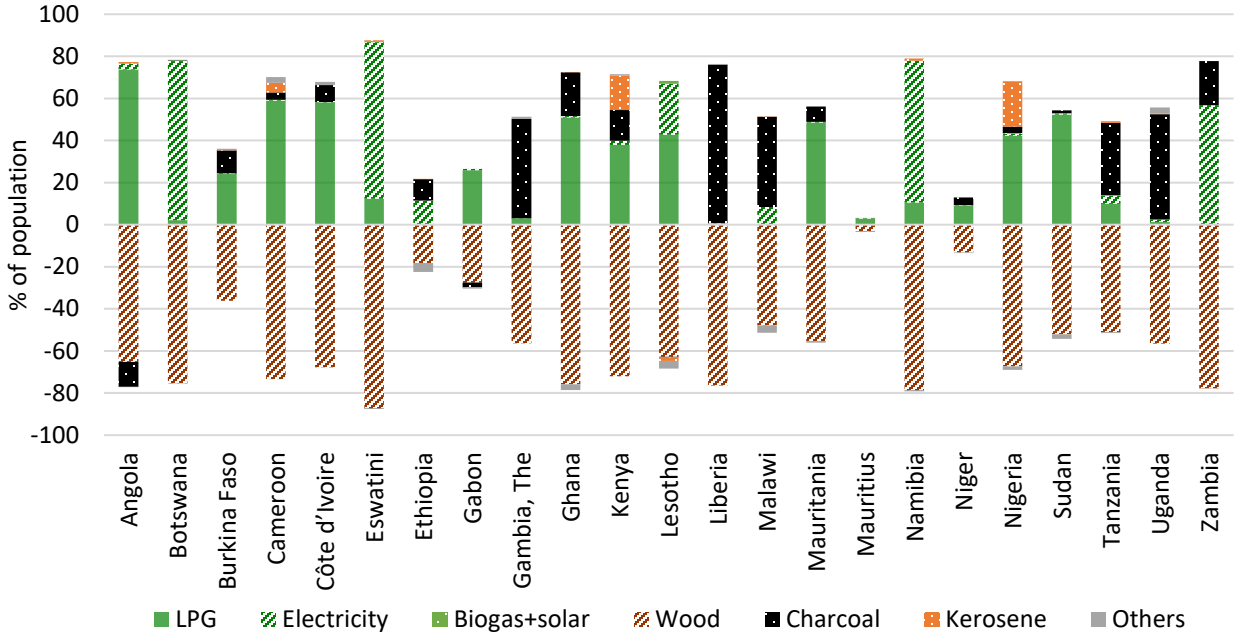
Source: World Bank staff calculations using household survey data

Note: The Botswana survey combines firewood and charcoal under wood. Expenditures per capita are annual. Clean = LPG, electricity, biogas, and solar; others = mostly agricultural residues and dung.

Figure A2.1 and Figure A2.2 in annex 2 reproduce Figure 2 for urban and rural areas, respectively. Unsurprisingly, far more urban residents use clean energy than their rural counterparts. Urban households on average are richer, have better access to infrastructure (electricity grid, paved roads for distribution of fuels), and enjoy lower prices for certain commercial fuels—for example, in countries with deregulated LPG pricing, bottled LPG would be cheaper in urban than rural areas because of greater economies of scale and close proximity to bottling plants and large depots. There are 11 countries in which more than half the urban population used clean cooking energy against 10 countries in which more than half used wood fuel or coal as the primary cooking fuel. By contrast, wood dominated cooking in rural areas irrespective of average per capita expenditures, with more than half the population using wood as their primary cooking fuel in 22 of 23 countries for which rural data were available. The only exception was South Africa, in which two-thirds of the rural population used clean cooking energy.

Comparison of cooking energy use between the rich and the poor in each country gives an indication of how rising income will likely shift the type of primary energy households use in that country. When the patterns of primary cooking energy use are compared between the top and bottom quintiles, predictably the top quintile cited LPG and electricity far more than the bottom quintile. In every country, a smaller proportion of the rich used wood as the primary cooking fuel than the poor. In several Southern African countries—Botswana, Eswatini, Namibia, Zambia, and, although not shown in the figure for a lack of data to compute quintiles, South Africa—rising income shifted households to cooking with electricity rather than LPG. In several low- and lower-middle-income countries, rising income shifted many households from wood to charcoal rather than to LPG or electricity. In Kenya and Nigeria, a greater proportion of the rich cooked with kerosene than the poor (Figure 3). The corresponding urban and rural results are shown in Figure A2.3 and Figure A2.4 in annex 2 with an associated commentary.

Figure 3 Difference between the top and bottom quintile in the percentage of people citing different forms of primary energy for cooking

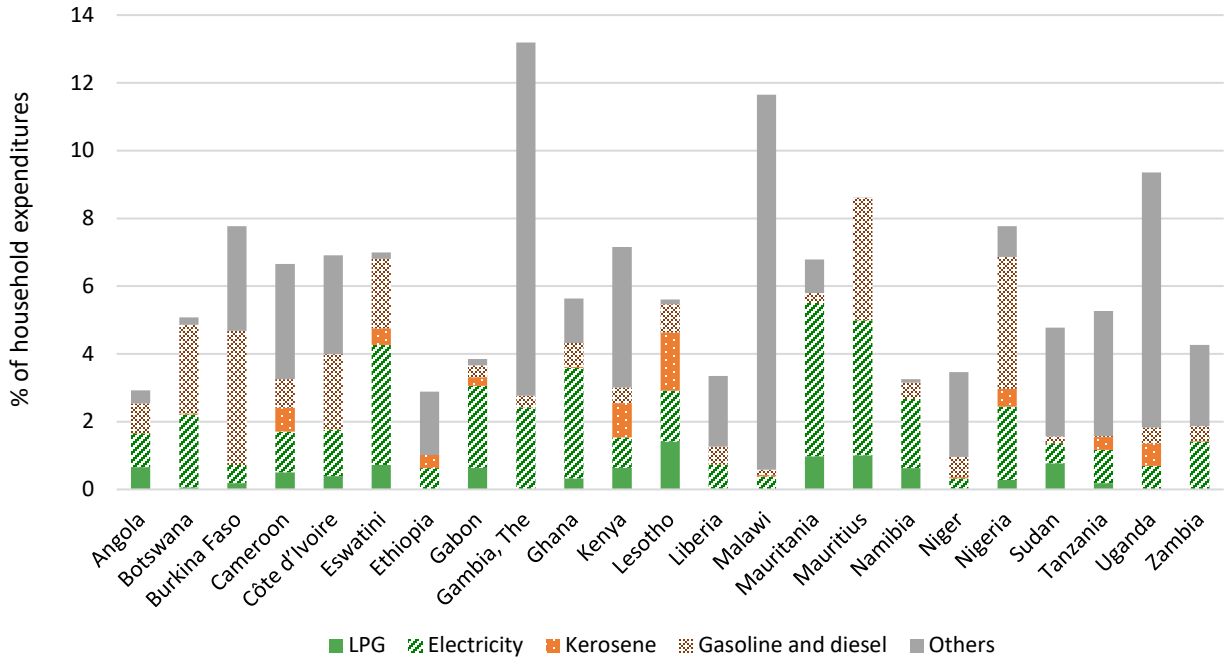


Source: World Bank staff calculations using household survey data

Note: For each energy category, the number shown is obtained by subtracting the share of the population in the bottom quintile from that in the top quintile. Others = mostly agricultural residues and dung.

The total share of household expenditures spent on energy averaged across all households (whether or not they used different forms of energy for which data were collected) varied from less than 4 percent in Angola, Gabon, and Sudan to almost 16 percent in The Gambia. In no country did LPG comprise the largest share. The surveys in 10 countries found the largest share had been spent on electricity and in another 10 countries on "others," which were mostly wood, charcoal, coal, and kerosene. The largest share spent on LPG was 2.1 percent in Lesotho (Figure 4).

Figure 4 Percentage of total household expenditures spent on different forms of energy



Source: World Bank staff calculations using household survey data.
Note: The expenditure shares are averaged across all households, including those reporting zero expenditures. Others = solid biomass and other fuels.

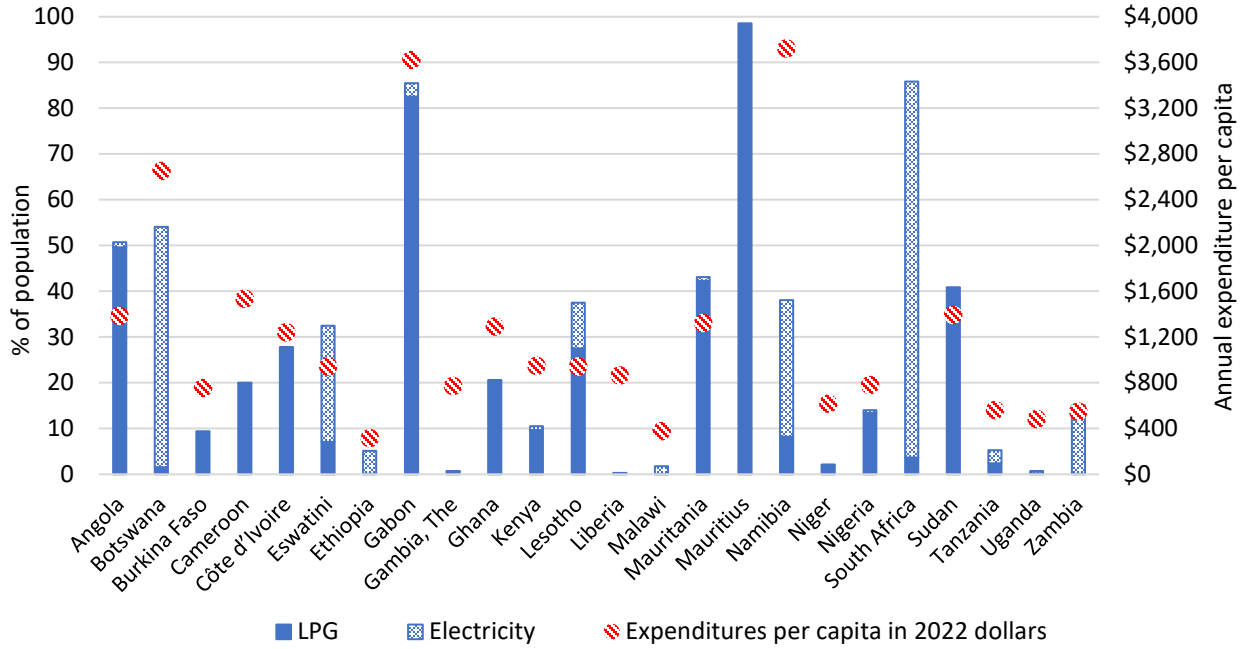
The urban and rural results on the energy expenditure shares can be found in Figure A2.5 and Figure A2.6, respectively, in annex 2. In urban areas, the energy expenditure share varied from less than 4 percent in Angola, Gabon, and Sudan to 16 percent in The Gambia. Electricity comprised the largest share in 11 countries, followed by "others" in nine and gasoline and diesel in three. By contrast, the share in rural areas varied from less than 2 percent in Angola (1.4 percent), Ethiopia (1.0 percent), and Liberia (1.9 percent) to 12 percent in Malawi. "Others" led the largest share in 14 countries, followed by gasoline and diesel in four countries, and finally by kerosene in two countries and electricity also in two countries. The expenditures on "others" should be interpreted with caution because they include imputed costs of freely acquired biomass, which is more readily available in rural areas. Urban Gambia and rural Malawi stand out for households spending more than 10 percent on "others"—comprising largely charcoal and wood in urban Gambia and wood in rural Malawi, with the latter likely to have included a significant proportion of freely acquired wood.

The total energy expenditure share in urban areas exceeded that in rural areas in 15 of 22 countries for which information was available, with the largest difference being 9.3 percentage points in Mauritania. Among the countries in which rural households reported spending more on energy than urban households, Malawi recorded the largest difference, with rural households spending on average 3 percentage points more on energy than urban households. This difference was driven by greater spending on firewood in

rural areas, much of it presumably representing imputed values of freely collected wood. An analysis of household energy use patterns in Malawi showed that the most common combination of energy sources for household use (not just for cooking but for all purposes) was electricity and charcoal in urban areas (29 percent of all urban households) and firewood only in rural areas (84 percent of all rural households), with no expenditures on kerosene or electricity reported by the latter group.

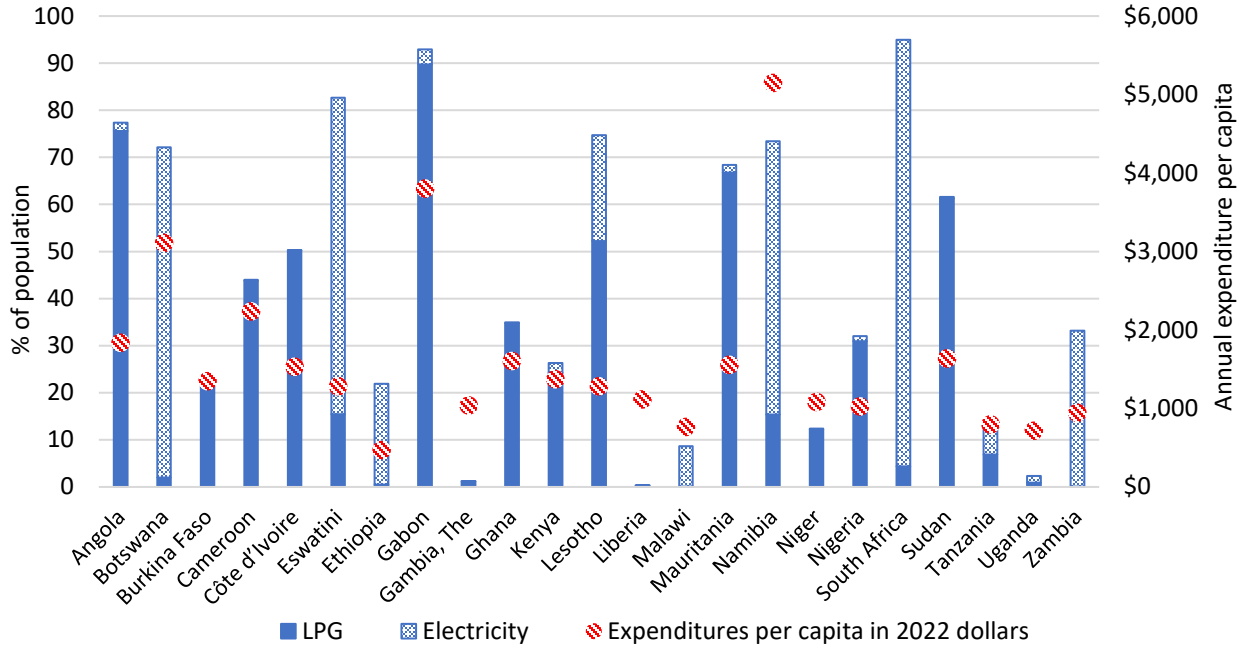
When confining examination to clean forms of energy, LPG dominated primary cooking energy in Angola, Gabon, and Mauritius, and electricity was dominant in Botswana and South Africa. In South Africa, between 2010 and 2018, the percentage of the total population living in households using LPG as the primary cooking fuel was consistently below 5 percent, fluctuating between 1.9 percent in 2011 to 4.3 percent in 2017 and averaging 3.2 percent. By contrast, the percentage of people living in households using electricity as the primary source of energy for cooking gradually rose from 69 percent in 2010 to 82 percent in 2018 during the same nine-year period. In most countries, either LPG or electricity dominated, leaving Tanzania as the only country where the preference was equally split between the two choices (Figure 5). The same qualitative patterns were seen but in larger percentages in urban areas (Figure 6), and conversely the population shares were much smaller in rural areas (Figure 7).

Figure 5 Percentage of people living in households that cited LPG or electricity as the primary source of energy for cooking and annual expenditures per capita



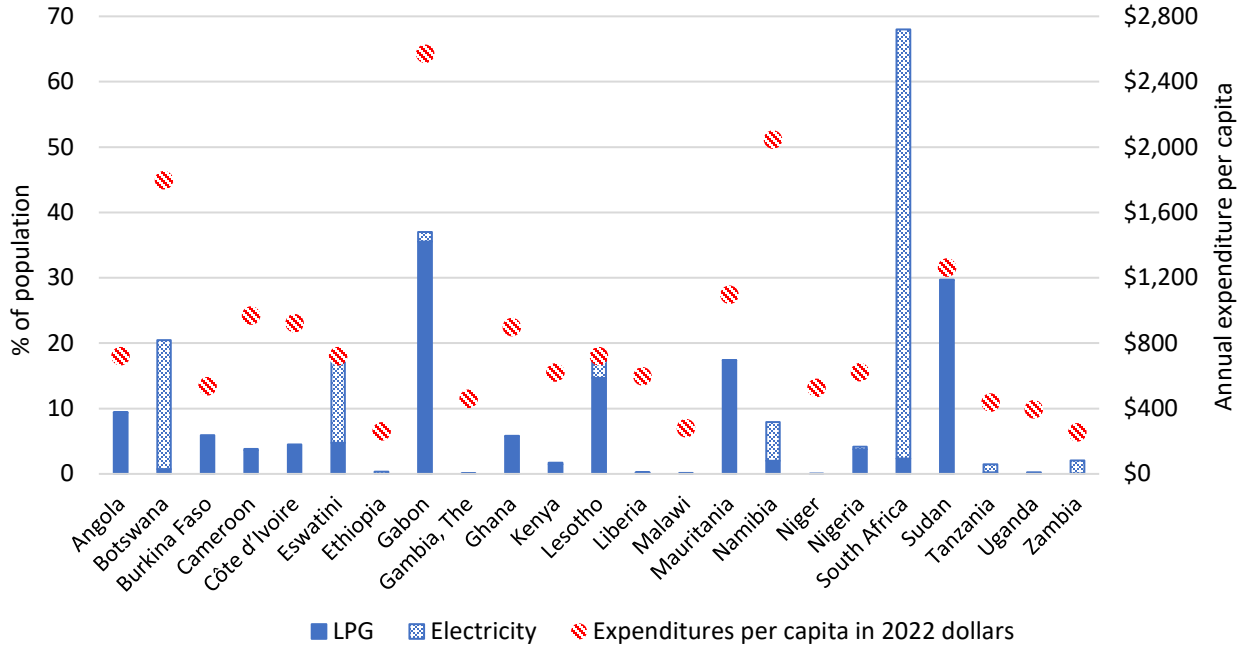
Source: World Bank staff calculations using household survey data.
Note: The South African survey did not ask enough questions to enable estimation of the total household expenditures.

Figure 6 Percentage of people living in households that cited LPG or electricity as the primary source of energy for cooking and annual expenditures per capita in urban areas



Source: World Bank staff calculations using household survey data.
Note: The South African survey did not ask enough questions to enable estimation of total household expenditures.

Figure 7 Percentage of people living in households that cited LPG or electricity as the primary source of energy for cooking and annual expenditures per capita in rural areas

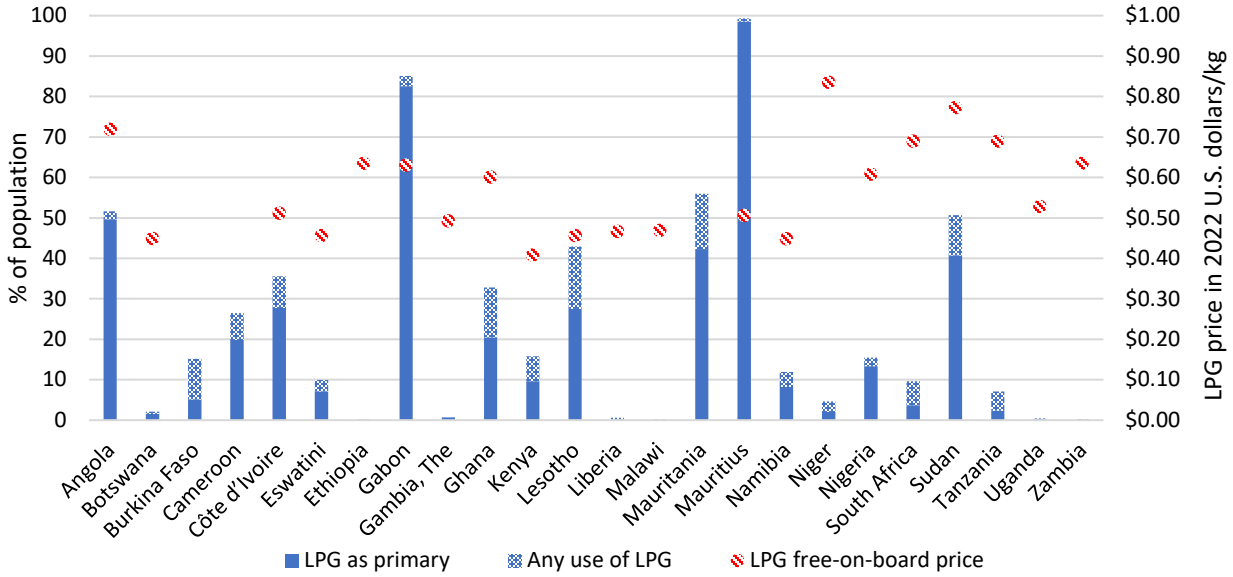


Source: World Bank staff calculations using household survey data.
Note: The South African survey did not ask enough questions to enable estimation of total household expenditures.

Comparison of households with evidence of LPG use and those who named LPG as the primary cooking fuel is shown in Figure 8. In Burkina Faso, Liberia, Niger, South Africa, Tanzania, and Zambia, less than

half of those using LPG used it as their primary cooking fuel. At the opposite end of the spectrum, Angola, Gabon, and Mauritius stood out as those in which the uptake of LPG was not only high but was also essentially synonymous with use of LPG as the primary cooking fuel.

Figure 8 Comparison of households using LPG in any capacity and those citing LPG as the primary cooking fuel



Source: World Bank staff calculations using household survey data and RIM LPG Intelligence Daily.
Note: LPG prices average Saudi Aramco contract prices for propane and butane in the month that is halfway through the survey period and converted to 2022 U.S. dollars using the U.S. GDP deflators.

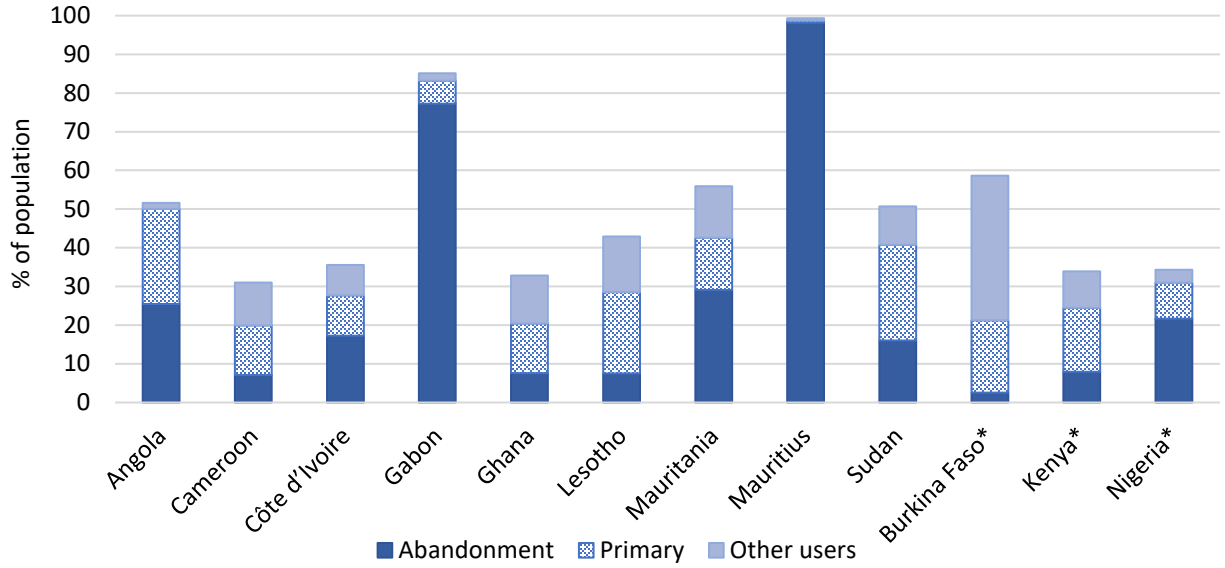
Because global LPG prices varied several-fold during the period covered by the surveys, the average Saudi Aramco contract prices for propane and butane in 2022 U.S. dollars per kg are also shown in Figure 8. Because the transportation, storage, and bottling costs also vary several-fold from country to country, compounded by price subsidies in some countries, the free-on-board LPG prices merely give indications of the global LPG price movements and some idea of end-user prices in countries with no subsidies at the time, which include southern African countries except Angola, Kenya, Liberia, Nigeria, Tanzania, and Uganda. As an extreme example of a very large difference between end-user prices and the Arab Gulf prices, the average of maximum retail prices of LPG established by the government of South Africa in 28 regional zones was higher than the Arab Gulf price by nearly US$1.30 per kg,[7] tripling the retail price from the Arab Gulf price and markedly higher than US$0.30 assumed in the calculation of annual household income needed for monthly purchases of 12.5 kg of LPG. By contrast, in Nigeria, where LPG prices have been deregulated for a long time, the difference was US$0.30 per kg.[8] The very high prices of LPG in South Africa and the neighboring countries (except Angola, where LPG has been heavily subsidized) and conversely historically reliable electricity and low electricity tariffs would also explain why few have chosen to cook with it and electricity has remained the most popular source of energy for cooking in Southern Africa.

[7] http://www.energy.gov.za/files/petroleum_frame.html.
[8] https://nigerianstat.gov.ng/elibrary.

Abandonment of Polluting Fuels

Abandonment of polluting fuels was examined in the context of adoption of LPG by taking the larger geographical area of the two areas (entire country or urban areas) in which 20 percent or more of the population cited LPG as the primary cooking fuel. There is a trade-off between coverage and representativeness, and the cut-off point of 20 percent was selected as a compromise between the two competing objectives—the lower the threshold level the greater the coverage, but the lower the statistical significance of the data. In the areas so selected, the analysis began with identification of all households using LPG in any capacity, followed by identification of those citing LPG as their primary cooking fuels, and finally those who were not only using LPG but had abandoned all polluting liquid and solid fuels (Figure 9). As mentioned in the study description, abandonment as defined and measured in this study is not confined to cooking and instead represents abandonment of polluting fuels for all household activities. There was considerable variation in the population shares across the areas, ranging from those where only a very small fraction of LPG users had abandoned polluting fuels to those where virtually everyone had abandoned them. The solid blue portion in the figure representing abandonment of polluting fuels varied from 2.6 percent in urban Burkina Faso to 98 percent in Mauritius. Urban Burkina Faso stood out for having a majority of LPG users being incidental users who did not use LPG as the primary cooking fuel. By contrast, in Angola, Gabon, Mauritius, and urban Nigeria, the vast majority of those using LPG at all used it as their primary cooking fuel.

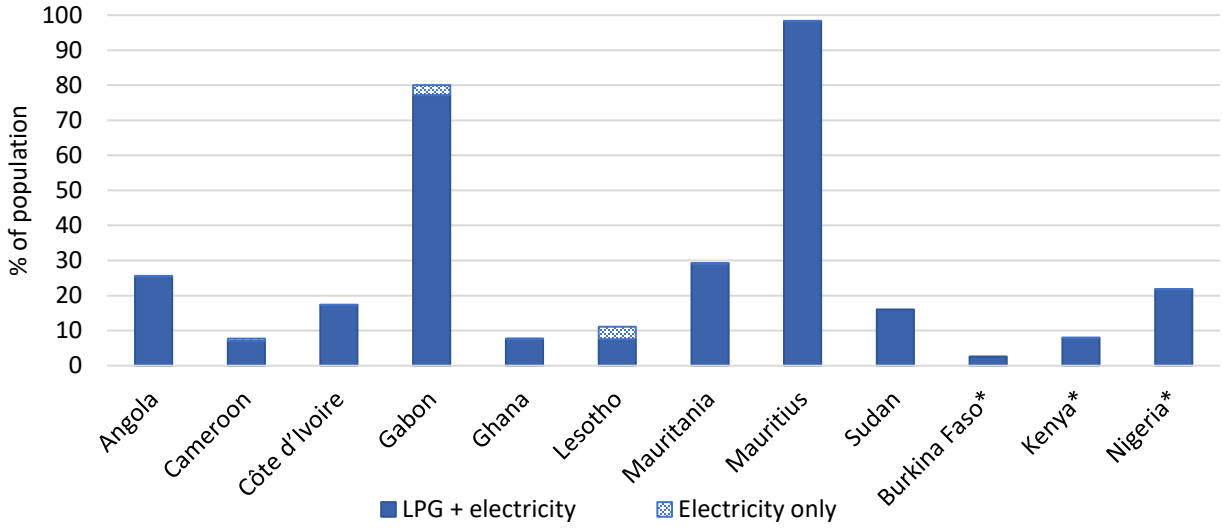
Figure 9 Breakdown of adoption of LPG: abandonment of polluting fuels, primary use, and all users of LPG



Source: World Bank staff calculations using household survey data.
Note: The analysis is confined to those areas—nationally or urban areas—where more than one-fifth of the population lived in households citing LPG as the primary cooking fuel. For the first nine countries, the entire sample is taken because the one-fifth threshold is met nationally. In Burkina Faso, Kenya, and Nigeria, the one-fifth threshold is met only in urban areas. Households abandoning polluting fuels include very few LPG users who did not cite LPG as their primary cooking fuel. However, the sum of abandonment and primary bars in the figure equals the percentage of the total population citing LPG as the primary cooking fuel. Taking Cameroon as an example, the figure shows that 31 percent of the population was using LPG in any capacity, 20 percent of the population cited LPG as the primary cooking fuel, and 7 percent used LPG and no other polluting liquid or solid fuels. Abandonment = percentage of people living in households that used LPG and had abandoned all forms of polluting fuels; primary = percentage of people living in households that cited LPG as their primary cooking fuel but had retained the use of polluting fuels; other users = percentage of people who reported non-zero expenditures on LPG but did not cite it as their primary cooking fuel and had retained the use of polluting fuels; * = urban areas only.

Ultimately the goal for universal access to clean energy is abandonment of polluting energy. This study therefore also examined if, in the countries selected for abandonment, there were other households who had not used LPG and used only electricity. The selection criterion—only those areas where one-fifth of the population cited LPG as their primary cooking fuel—meant exclusion from the sample of Botswana, Eswatini, Namibia, South Africa, and Zambia, where few cooked with LPG and most households reliant on clean energy used electricity. As a result, there were few households that had used electricity to meet all their household needs (Figure 10).

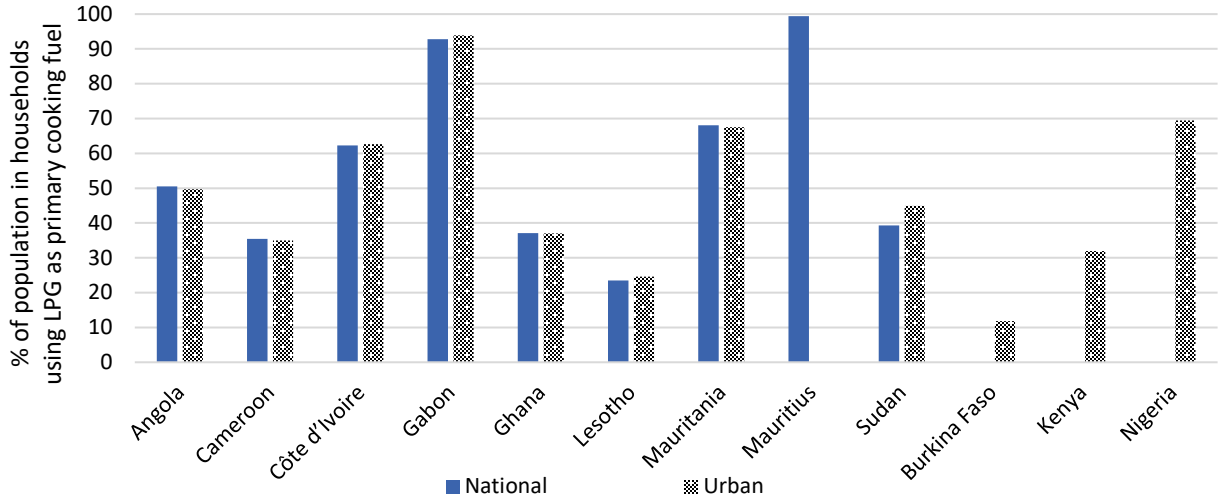
Figure 10 Share of population abandoning polluting fuels



Source: World Bank staff calculations using household survey data.
Note: * = urban areas only.

Another question is the extent to which adoption of LPG as the primary cooking fuel is correlated with abandonment of polluting fuels (Figure 11). Virtually all households citing LPG as their primary cooking fuel kept using polluting fuels in urban Burkina Faso. In Cameroon, Ghana, urban Kenya, and Lesotho, more than three-fifths of the population continued to use polluting fuels. By contrast, virtually all households in Mauritius had abandoned polluting energy for all activities, closely followed by Gabon. In Côte d'Ivoire, Mauritania, and urban Nigeria, once a household adopted LPG as the primary cooking fuel, more than three-fifths abandoned all other fuels. When the results were broken down by expenditure quintile, there were no marked differences between lower and higher quintiles. Such findings about expenditure quintiles, however, should be interpreted with caution because the sample size of those citing LPG as the primary cooking fuel is small in lower quintiles in many countries. For example, the percentage of the population living in households in the bottom quintile citing LPG as the primary cooking fuel exceeded 10 percent only in Gabon, Mauritius, and Sudan, with Cameroon and Ghana reporting less than 1 percent. In such cases, the lower quintile figures are not statistically meaningful.

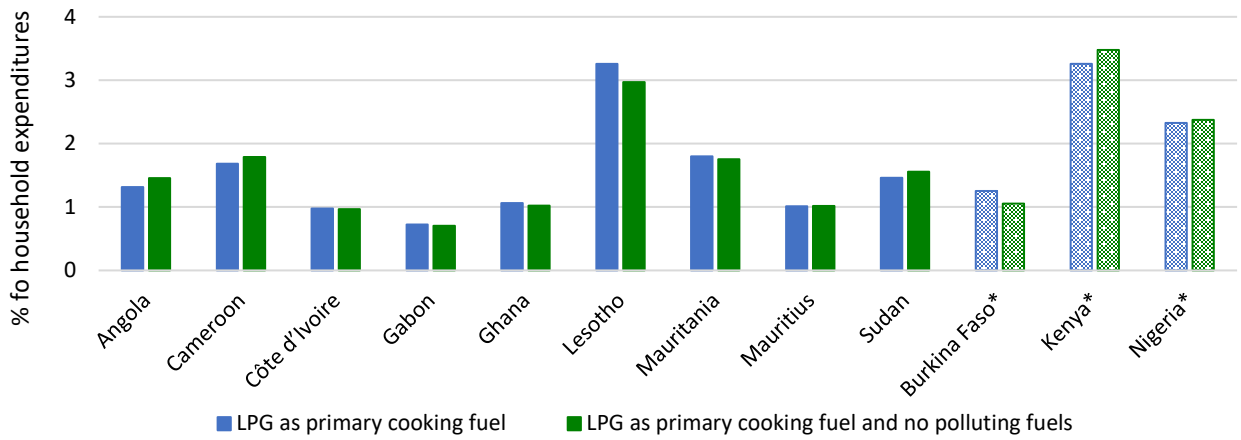
Figure 11 Percentage of people living in households that cited LPG as the primary cooking fuel who are estimated to have abandoned polluting fuels



Source: World Bank staff calculations using household survey data.
Note: The analysis is confined to those areas—nationally or urban areas—where more than one-fifth of the population lived in households citing LPG as the primary cooking fuel. Only national results were available for Mauritius. In Burkina Faso, Kenya, and Nigeria, the one-fifth threshold was met only in urban areas and hence national results are not shown.

Analysis of LPG expenditure shares shows that the 5 percent threshold suggested in the multi-tier framework as an upper limit for affordability was not breached in any of the sampled areas. In Figure 12, the blue bars represent LPG expenditure shares of all households citing LPG as the primary cooking fuel, whether or not they had abandoned polluting fuels. The green bars take the segment of the households in the blue bars who had abandoned polluting fuels. The differences are small. This finding seems surprising at first. First, abandonment of polluting fuels would be expected to increase the quantities of LPG purchased, everything else being equal. Second, measurement errors caused by asking households how much they had spent on LPG in the previous month would be expected to be smaller for those using only LPG: many more of those who had not abandoned other fuels would be expected to purchase LPG less frequently than once a month, resulting in under-estimation of expenditures on LPG, although over-estimation by those who happened to have purchased LPG in the previous month might have offset such under-estimation. In countries where a large fraction of those using LPG as the primary cooking fuel had not abandoned polluting fuels despite spending little on LPG—Cameroon, Sudan, and urban Burkina Faso—it is not clear that financial considerations had prevented these households from switching entirely to LPG (and electricity) for cooking.

Figure 12 Percentage of total household expenditures spent on LPG by all those citing LPG as the primary cooking fuel and those citing LPG as the primary cooking fuel who had abandoned polluting fuels



Source: World Bank staff calculations using household survey data.
Note: * = urban population only.

To probe the above findings further, data from the top two quintiles in regions with enough households that had abandoned polluting fuels—who were essentially using only LPG and electricity—were analyzed. Table 1 compares the statistics related to spending on LPG and electricity by two groups of households: (1) those who were consuming LPG (whether as the primary cooking fuel or in any other capacity) and had abandoned all polluting fuels, and (2) those who cited LPG as their primary cooking fuel but continued to use polluting fuels. Mauritius and Burkina Faso are omitted in the table, the former because too few people had not abandoned polluting fuels and the latter because too few people had abandoned polluting fuels. In the remaining 10 regions, the percentage of the total population in each quintile that belonged to the first group (abandoning polluting fuels) ranged from a mere 5 percent in urban Kenya in the fourth quintile to 85 percent in Gabon. The highest LPG expenditure share of 4.6 percent in urban Kenya was below the 5 percent threshold for affordability. At the opposite end of the spectrum, the LPG expenditure share was only 0.7 percent in Gabon—leading to about 85 percent of the population in each quintile abandoning polluting fuels—and, although not included in Table 1, in Mauritius where 98 percent of the entire population had abandoned polluting fuels, less than 1 percent in the top two quintiles. The multi-tier framework also sets a ceiling of 5 percent for spending on electricity, making the ceiling on spending on cooking energy and electricity 10 percent. This 10 percent limit was also not breached in any of the quintiles. However, spending on electricity in Ghana in the fourth quintile and Mauritania in both quintiles exceeded 5 percent.

Households that had abandoned polluting fuels spent more on electricity than on LPG except in Sudan, urban Kenya, and Urban Nigeria. Those abandoning polluting fuels on average were richer in the fifth quintile but not in the fourth quintile, where the two groups of households had nearly identical expenditures per capita. Total household expenditures, however, were nearly always lower among those abandoning polluting fuels because these households were markedly smaller. In absolute terms, these smaller households spent less on LPG—which likely suggests they consumed smaller quantities—than those using polluting fuels. They also spent—and presumably consumed—more on electricity in five countries in the fourth quintile and in four countries in the top quintile. In terms of expenditure shares, households abandoning polluting fuels had spent more on electricity in all but one country and more on LPG in half the countries in both fourth and fifth quintiles than those who continued to stack fuels.

Table 1 Comparison of LPG-using households who had abandoned polluting fuels and those who cited LPG as their primary cooking fuels and continued to use polluting fuels

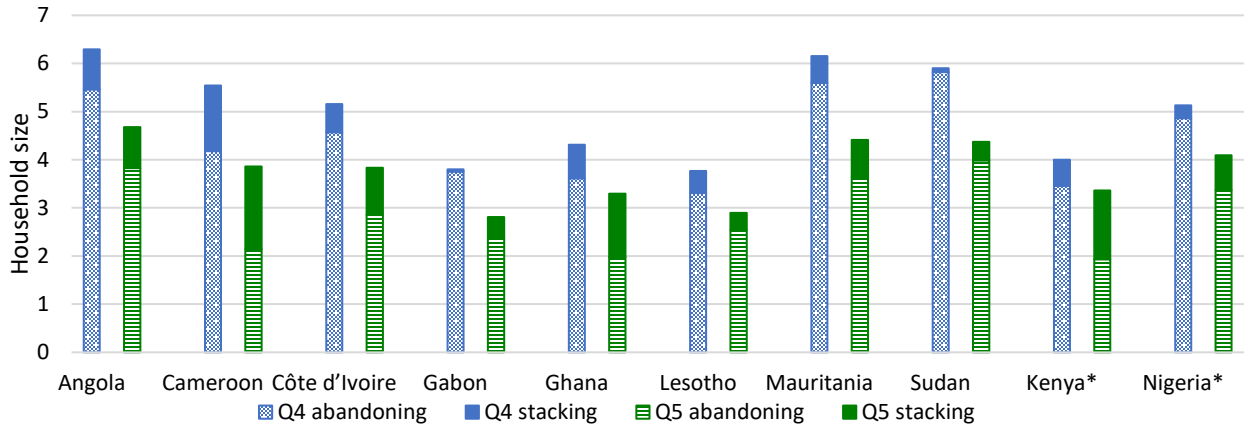
Item	Angola	Cameroon	Côte d'Ivoire	Gabon	Ghana	Lesotho	Mauritania	Sudan	Kenya[a]	Nigeria[a]
Quintile 4										
People who live in households that used LPG and had abandoned polluting fuels										
% of quintile 4 population	36	7	22	85	10	10	40	22	5	18
% LPG expenditure share	1.4	2.3	1.0	0.7	1.1	3.3	1.9	1.6	4.6	2.7
% Electricity expenditure share	2.1	2.5	2.2	2.8	5.3	3.9	7.9	1.4	2.1	1.8
Ratio of abandoning households to those retaining polluting fuels										
Spending on LPG	0.93	0.93	0.92	0.78	0.81	0.87	0.90	1.1	0.99	1.1
Spending on electricity	1.0	1.1	1.1	0.97	1.1	0.99	0.97	1.6	0.86	1.3
LPG expenditure share	1.2	1.2	0.92	0.67	1.0	1.0	1.0	1.2	1.2	1.2
Electricity expenditure share	1.3	1.1	1.2	1.3	1.2	1.7	1.1	1.5	1.0	1.4
Expenditures per capita	0.99	1.0	0.99	1.0	0.98	0.99	0.97	1.0	0.97	1.0
Household expenditures	0.86	0.89	0.99	0.84	0.85	0.90	0.90	0.99	0.79	0.95
Quintile 5										
People who live in households that used LPG and had abandoned polluting fuels										
% of quintile 5 population	43	26	45	84	21	14	45	30	15	40
% LPG expenditure share	1.1	1.7	0.9	0.7	1.0	2.1	1.7	1.4	3.3	2.2
% Electricity expenditure share	2.0	1.8	2.0	3.2	4.3	2.7	8.7	1.2	2.2	1.9
Ratio of abandoning households to those retaining polluting fuels										
Spending on LPG	1.4	0.74	0.88	0.87	0.66	0.81	0.77	1.0	0.85	1.0
Spending on electricity	0.89	0.62	0.95	1.0	0.78	1.2	1.1	1.4	0.96	1.1
LPG expenditure share	1.3	1.2	0.98	0.90	0.97	0.85	0.92	1.1	1.1	1.1
Electricity expenditure share	1.2	0.93	1.2	1.4	1.1	1.5	1.3	1.4	1.1	1.2
Expenditures per capita	1.3	1.2	1.2	1.0	1.3	1.0	1.0	1.1	1.4	1.2
Household expenditures	1.0	0.67	0.87	0.85	0.74	0.87	0.79	0.97	0.81	0.90

Source: World Bank staff calculations using household survey data.
Note: The ratio for a given item is that of those using LPG and had abandoned polluting fuels to that of those citing LPG as the primary cooking fuel and retained the use of polluting fuels. Expenditures on LPG and electricity are not deflated to avoid geospatial deflators markedly altering what households had spent. Ratios exceeding 1 (namely metrics for those who had abandoned polluting fuels were larger than those who had not) are shaded in light blue. To avoid giving a false sense of accuracy, only two significant figures are shown for all statistics except the percentage of the total population in the first line for each quintile, for which no decimals are retained.
a. Urban households only.

In a given expenditure quintile, households using LPG as their primary cooking fuel but retaining polluting fuels could even have nearly twice as many members as LPG-using households that had stopped fuel stacking, and in no country were fuel-stacking households on average the same size or smaller than

those who had stopped fuel stacking, perhaps reflecting the ease of cooking with LPG for small families. Figure 13 compares household size for the top two expenditure quintiles in the countries covered in Table 1. The top quintile in Cameroon, Ghana, and urban Kenya had the largest disparity in household size between those abandoning and those stacking polluting fuels. Table 1 shows that households abandoning other fuels in the top quintile in these three countries spent considerably less on LPG in absolute terms than fuel-stacking households, but up to 20 percent more in terms of LPG expenditure shares. Given the LPG expenditure share was only 1 percent in Ghana in the top quintile even for those who had abandoned polluting fuels and yet four-fifths of all households in the same quintile had retained the use of polluting fuels, affordability may not be the main reason for fuel stacking.

Figure 13 Comparison of sizes of households abandoning versus stacking polluting fuels



Source: World Bank staff calculations using household survey data.
Note: The solid portions are incremental household sizes for those staking fuels. For example, in the top quintile in Cameroon, the average size of households abandoning polluting fuels was 2.1, and that of the households stacking fuels was 3.9. * = urban households only; Q4 = quintile 4; Q5 = quintile 5; abandoning = LPG-using households that had abandoned polluting fuels; stacking = households citing LPG as their primary cooking fuel and were using polluting fuels in parallel.

When household sizes are compared across expenditure quintiles, unsurprisingly it becomes clear that there is no simple pattern with respect to household size. In every one of the 10 countries, the average size of the households with fuel stacking in the top quintile was smaller than that of LPG-consuming households abandoning all other fuels in the fourth quintile. This can be seen by comparing the full height of the green bar in Figure 13 with the patterned (non-solid) portion of the blue bar in every country. That is, the latter group of households was cooking exclusively with LPG and electricity despite being poorer in every case and larger on average than those in the top quintile who kept on using other fuels. Possible explanations include differences in market conditions and personal preferences. With respect to market conditions, some households may live closer to LPG retail outlets than others or near LPG retailers who respond immediately to requests for refills, making it easier to abandon other fuels. For differences in personal preferences, some families may like dishes that are difficult or costly to cook with LPG more than others. An example is tuo zaafi—a popular dish in northern Ghana, the goat stew of which is cooked over many hours and making of the sauce requires vigorous stirring—and such families may own stable and large wood-burning stoves to make these traditional dishes in large quantities.

What combinations of energy sources are most common among households? To answer this question, all possible combinations of energy choices were examined in several countries. The distinct combinations numbered as many as 158 in Sudan, although the top 17 combinations covered 90 percent of all households. Table 2 shows results for seven of the countries studied for abandonment of polluting fuels, listing top-ranking combinations observed in order of decreasing frequency. The combinations are

enumerated until two-thirds of the total population are covered, subject to there being at least two combinations containing LPG. As expected, almost all households using LPG in these top choices also used electricity. Lesotho was one exception where the third most common combination was LPG and kerosene only, with kerosene presumably used for lighting. In households using energy sources in addition to electricity and LPG, typically only one other fuel was used, that fuel being charcoal or kerosene. In Angola, where LPG has been heavily subsidized for decades and spending on LPG is only barely more than 1 percent of total household expenditures, the continuing use of charcoal by households using LPG may signal a cultural preference. In Nigeria, where neither kerosene nor LPG has been subsidized for many years, continuing use of kerosene might possibly suggest unreliable LPG supply.

Table 2 Ranking of household energy choices

	Energy	% of HHs	Energy	% of HHs	Energy	% of HHs	Energy	% of HHs
Rank	Angola		Cameroon		Ghana		Lesotho	
1	Wood	32.4	Wood	15.9	Electricity-charcoal	20.9	Kerosene-wood	21.0
2	LPG-electricity	19.7	Wood-kerosene	15.6	LPG-electricity-charcoal	20.3	LPG-electricity-kerosene	20.1
3	LPG-electricity-charcoal	16.4	Electricity-wood-kerosene	13.0	Electricity-wood	12.4	LPG-kerosene	7.9
4			LPG-electricity	11.5	LPG-electricity	12.1	Electricity-kerosene	7.3
5			Electricity-wood	8.2			Kerosene	4.6
6			LPG-electricity-kerosene	4.0			Kerosene-wood-coal	4.5
Rank	Sudan		Urban Kenya		Urban Nigeria			
1	LPG-electricity-charcoal	17.3	Electricity-charcoal-kerosene	17.2	LPG-electricity	25.2		
2	LPG-electricity	16.6	Electricity-kerosene	12.2	Kerosene-electricity	22.0		
3	Wood-charcoal	10.9	LPG-electricity	12.2	Wood-electricity	9.6		
4	Wood	9.5	LPG-electricity-kerosene	7.9	Kerosene-electricity-wood	8.2		
5	LPG-electricity-wood-charcoal	7.6	LPG-electricity-charcoal	7.8	LPG-electricity-kerosene	7.7		
6	Electricity-wood-charcoal	5.9	Charcoal-kerosene	6.6				

Source: World Bank staff calculations using household survey data.
Note: Ranking is in order of decreasing number of households falling under any given combination. Only the top choices covering about two-thirds of all households, subject to inclusion of at least two combination choices containing LPG, are shown. The households in Nigeria add up to 73 percent to show two categories of LPG users. HHs = households.

A more comprehensive list of combinations of energy sources used by households, taking Ghana for illustration, can be found in Table A2.1 in annex 2. There were 35 distinct combinations of household energy sources in urban areas, 43 in rural areas, and 48 nationally. Not all combinations are shown because, although the questionnaire included sawdust, animal waste, and other fuels as possibilities, fewer than 1 percent of all households in urban areas, rural areas, and nationally reported non-zero expenditures on these fuels or cited them as their primary fuels for cooking. There were so few such households that they are omitted from the table.

Summary and Concluding Observations

Stacking of electricity and fuels is common in many countries, resulting in as many as 158 distinct patterns of household energy use identified in one country studied. Because the recall period for expenditures on energy is almost always one month, use of some forms of energy and especially LPG is not necessarily accurately captured. Asking about primary sources of energy for lighting and cooking is important and informative but reveals little about multiple fuel use. To understand the degree of fuel stacking, adding one more question on all forms of energy used may provide valuable information without adding an undue burden on data collection. For example, the question about the primary source of energy for cooking may be followed immediately by a question about which energy items in the list of options for cooking had been used by the household in the recent past, perhaps covering the previous 12 months to catch seasonality.

Almost all LPG users also use electricity. There are several reasons. First, the absence of grid electricity is emblematic of inadequate infrastructure in general. Reliable LPG supply requires connection to paved roads, but those living in areas without grid electricity are less likely to be living near well-connected paved roads and hence less likely to find LPG outlets nearby. Those not using electricity tend to be poorer, again making them less likely to use LPG. In addition, households prioritize electricity consumption over cooking fuels (Kojima 2021a) so that those who can afford LPG are likely to choose to pay for electricity first before adopting LPG. In Sub-Saharan Africa, where electricity and LPG may become two main energy sources for achieving universal access, expansion of access to LPG will likely go hand in hand with expansion of reliable electricity services.

More than half of the population in all but five of the 24 countries studied used wood, charcoal, kerosene, and other solid fuels as primary cooking fuels, with wood and charcoal most frequently cited. A recent analysis of the Multiple Indicator Cluster Surveys found that one form of energy dominated clean cooking energy and there was no even split among two or more options, except in Kazakhstan (Kojima 2021c). This study on Sub-Saharan Africa similarly found that either LPG or electricity overwhelmingly dominated clean cooking energy selection in every country except Tanzania. Unlike other regions of the world with natural gas for urban households, where rural households may cook with LPG in the absence of natural gas pipelines or reliable electricity and urban households cook with natural gas or electricity, the clean cooking fuel use patterns of urban and rural households were similar in Sub-Saharan Africa. In particular, if urban households did not cook with LPG and used electricity instead, rural households did not cook with LPG either.

Averaged across all households, spending on electricity far exceeded that on LPG with the exception of Kenya, Lesotho, and Sudan. This pattern would be consistent with electricity being prioritized before LPG. Total spending on household fuels excluding gasoline and diesel exceeded 8 percent in three countries: The Gambia, Malawi, and Uganda, and all on account of expenditures on charcoal and firewood. To the extent that firewood may not have been purchased and spending instead represents the imputed values of collected firewood, these expenditures would not represent cash layouts, thereby making comparison with the 5 percent threshold for affordability more ambiguous. Imputed values are expected to be more common in rural areas, such as rural Uganda where spending on firewood alone amounted to 6.6 percent, consisting of 5.8 percent by the non-poor but as much as 9.0 percent by the rural poor.

One interpretation of the findings in this study is that once a critical mass of LPG users is reached—Figure 8 may suggest half the population—adoption of LPG as the primary source of energy for cooking by those using LPG is more likely. Of the 24 countries sampled, there were 12 countries in which more

than one-fifth of the population, either nationally (nine countries) or in urban areas (three countries), cited LPG as the primary cooking fuel. In these areas, use of LPG was synonymous with the choice of LPG as the primary cooking fuel in Angola (where LPG has been heavily subsidized for years), Gabon, and Mauritius (where virtually all LPG using-households cited LPG as their primary cooking fuel); Gabon and Mauritius were also the two richest countries among those in which LPG was the primary clean energy for cooking. These countries were followed by urban Nigeria (90 percent of those using LPG used it as the primary cooking fuel), Sudan (80 percent), Côte d'Ivoire (78 percent), Mauritania (76 percent), urban Kenya (72 percent), Lesotho (64 percent), Cameroon (64 percent) and Ghana (62 percent). The only exception was urban Burkina Faso, where two-thirds of those using LPG had cited other fuels as their primary cooking fuels and the use of charcoal and firewood dominated even in the top urban quintile. Given the LPG expenditure shares of those using LPG as their primary cooking fuels in urban Burkina Faso were much lower than those in urban Kenya or Nigeria, the behavior of urban households in Burkina Faso may represent market factors, such as a lack of readily available LPG, as well as cultural preferences.

Confining the analysis to those expenditure quintiles in which there are many users of LPG as their primary cooking fuel, LPG-using households that had abandoned polluting fuels spent less on LPG than those citing LPG as their primary cooking fuel and retaining the use of other fuels. This likely suggests that the households abandoning other fuels consumed smaller quantities of LPG, although the possibility that they paid lower unit costs cannot be ruled out. In Cameroon, Gabon, Lesotho, and Mauritania, households in the top quintile abandoning polluting fuels spent less on LPG than those in the fourth quintile citing LPG as the primary cooking fuel and continued to stack fuels. It seems counter-intuitive that those who were not stacking fuels consumed less LPG than those who were using other fuels in parallel, particularly when the former households are much richer (belonging to the top quintile) than the latter (belonging to the fourth quintile). An important finding is that households that had abandoned other fuels were consistently smaller than those that had not in each quintile, and in some countries almost half as small. Although there are economies of scale in cooking, cooking for small families would nevertheless require less energy than cooking for large families. Large multi-burner stoves being able to accommodate large pots are also less likely to be needed when cooking for a family of only two or three. In the top quintile, the households abandoning polluting fuels were richer on the basis of expenditures per capita but had smaller total household expenditures because of their smaller household sizes. In half the countries, this resulted in higher LPG expenditure shares than those of fuel-stacking households. Nevertheless, the LPG expenditure shares among those who had abandoned polluting fuels remained below the 5 percent threshold for affordability in all countries, and in several countries the expenditure shares were markedly below 5 percent.

The low LPG expenditure shares could be seen as suggesting considerable scope for transitioning fully to exclusive use of clean cooking energy in the top 40 percent of the population. While the two countries with the largest proportion of the population abandoning polluting fuels had the smallest LPG expenditure shares—less than 1 percent in both Gabon and Mauritius—there was no obvious relationship in other countries between LPG expenditure shares and the percentage of the population abandoning polluting fuels. For example, although those in the top two quintiles in Ghana abandoning polluting fuels spent only 1 percent of their total expenditures on LPG, they comprised 15 percent of the population in these quintiles, while in Mauritania households abandoning other fuels in the top two quintiles spent close to 2 percent on LPG and yet accounted for more than 40 percent of the population, despite the expenditures per capita in these two countries being about the same in 2022 U.S. dollars (Table A.1).

The relatively low LPG expenditure shares of those abandoning other fuels suggest that, once a sizable portion of the population starts using LPG as the primary cooking fuel, incremental steps rather than major interventions may be sufficient to facilitate abandonment of polluting fuels, thereby achieving the objectives of universal access set forth in SDG 7.1. Those adopting LPG as the primary cooking fuel will be the better-off in Sub-Saharan Africa, but abandonment of all polluting fuels by 20–40 percent of the population would be a major achievement. There are several implications for government policy:

- There are many households who can afford LPG and whose expenditures on LPG are far below the 5 percent threshold for affordability and yet they continue to use polluting fuels. For a family of four, the minimum annual income of US$5,400 mentioned in association with Figure 1 translates to US$1,350 per capita, which is exceeded in in urban areas in 10 countries and nationally in seven countries surveyed in this paper (excluding South Africa). Government policies to promote greater use of LPG by such households need not involve financial incentives and should focus rather on improving market conditions, such as increasing fair and healthy competition—which will drive down costs and pass on lower costs to consumers—and supply reliability.
- One co-benefit of promoting general use of LPG—even if lower-income households use the fuel only incidentally—may be the resulting greater economies of scale, which in turn could make LPG more readily available (and the supply more reliable) as well as reduce costs. The first step in using LPG as the primary cooking fuel and eventually abandoning polluting liquid and solid fuels is to start using it. Lower-income households could be assisted by targeted conditional cash transfer schemes, such as those implemented in El Salvador, Peru, and elsewhere (Kojima 2021a), rather than fuel price subsidies, which distort market incentives.
- For abandonment of polluting fuels, this study did not find evidence that making LPG any cheaper by increasing subsidies would achieve much. There seem to be many households for whom the decision not to abandon polluting fuels does not appear to be based primarily on the question of affordability.
- Over the long run, LPG as a fossil fuel will be a transition fuel to a decarbonized economy. Southern Africa shows that historically reliable and affordable electricity may enable households to skip LPG. The complementarity between electricity and LPG, if not eventual substitution of electricity for LPG, should be considered when developing government policies for LPG.

As recent global fuel price movements show, the greatest barrier to uptake of LPG—high price volatility and high prices for many months or years on end depending on the global market situation—remains. This is all the more reason that governments cannot subsidize their way out of the problem of low access to clean energy. Instead, governments can pursue policy actions that would be beneficial under all circumstances—establish an enabling regulatory environment, enforce fair rules and standards on all LPG suppliers, monitor and penalize those who underfill LPG cylinders or fail to maintain cylinders for safety, and promote of hospitality rules and non-discriminatory third-party access to large infrastructure.

Annex 1: Survey Descriptions and Expenditure Findings

The survey descriptions and annual household expenditures for capita are shown in Table A.1. Expenditures in U.S. dollars are computed by converting the expenditures in the local currency to U.S. dollars using the official exchange rate averaged over the survey months first, and then adjusted to 2022 U.S. dollars using the U.S. GDP deflator applicable midway through the survey period. The dollar conversion of annual per capita expenditures should be treated with caution because not all countries had deregulated foreign exchange. For example, Sudan had multiple exchange rates at the time of the survey, which in turn were much more over-valued than the parallel market rate (IMF 2014, 2016).

Table A.1 Household surveys analyzed

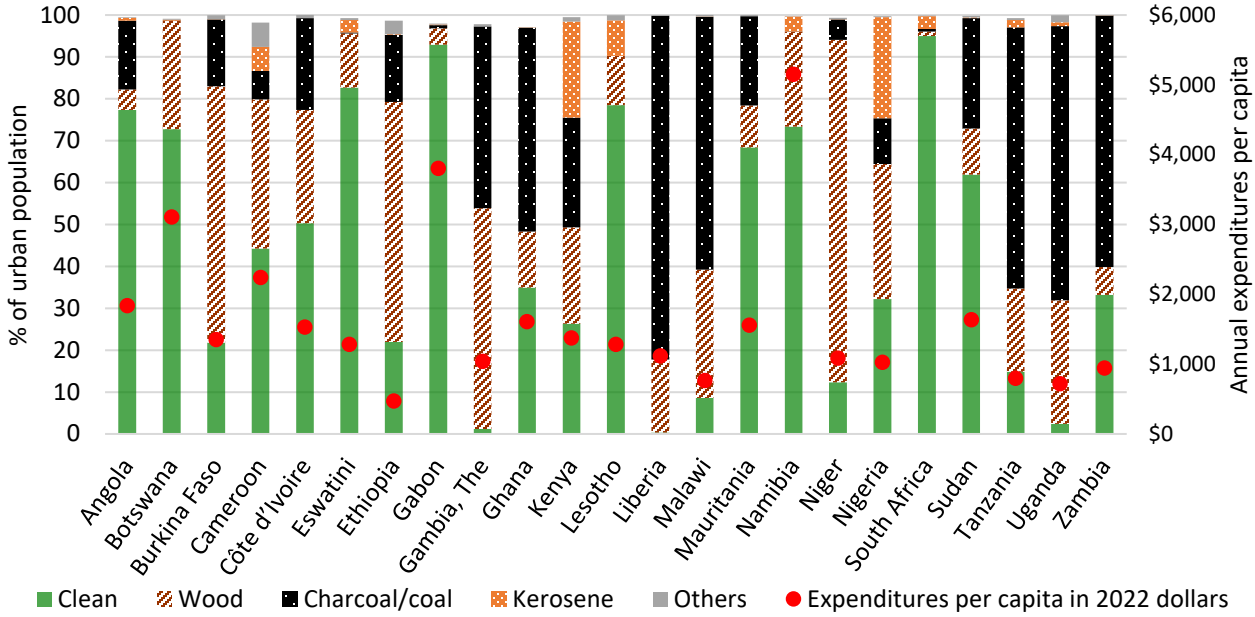
Country	Name of the survey	Survey start date	Survey end date	Annual per capita expenditure, 2022 US$		
				Urban	Rural	National
Angola	Inquérito Combinado de Despesas, Receitas e Emprego em Angola 2018/2019	Mar 2018	Feb 2019	$1,837	$720	$1,385
Botswana	Botswana Multi-Topic Household Survey 2015/16	Nov 2015	Oct 2016	$3,107	$1,797	$2,654
Burkina Faso	Enquête Multisectorielle Continue 2014	Jan 2014	Dec 2014	$1,348	$536	$758
Cameroon	Quatrième Enquête Camerounaise Auprès des Ménages 2014	Oct 2014	Dec 2014	$2,238	$968	$1,535
Côte d'Ivoire	Enquête Harmonisée sur les Conditions de Vie des Ménages (EHCVM) - 2018/2019	Sep 2018	Jul 2019	$1,531	$923	$1,242
Eswatini	Household Budget Survey	Jan 2017	Feb 2018	$1,280	$721	$942
Ethiopia	Socioeconomic Survey 2015-2016, Wave 3	Sep 2015	Apr 2016	$470	$260	$318
Gabon	Enquête Gabonaise pour l'Evaluation et le Suivi de la Pauvreté 2017	Jul 2017	Dec 2017	$3,801	$2,571	$3,624
Gambia, The	Integrated Household Survey on Consumption Expenditure and Poverty Level Assessment 2015/16	Apr 2015	Apr 2016	$1,037	$460	$774
Ghana	Ghana Living Standards Survey	Oct 2016	Oct 2017	$1,605	$899	$1,294
Kenya	Integrated Household Budget Survey 2015-2016	Sep 2015	Aug 2016	$1,373	$621	$950
Lesotho	Household Budget Survey	Jan 2017	Feb 2018	$1,280	$721	$942
Liberia	Household Income and Expenditure Survey 2016	Jan 2016	Dec 2016	$1,114	$597	$864
Malawi	Fourth Integrated Household Survey 2016-2017	Apr 2016	May 2017	$764	$280	$379
Mauritania	Enquête Permanente sur les Conditions de Vie des Ménages (EPCV) 2014	Apr 2014	Jan 2015	$1,555	$1,097	$1,325
Mauritius	Household Budget Survey 2017	Jan 2017	Dec 2017	n.a.	n.a.	$4,066
Namibia	Household Income and Expenditure Survey 2015-2016	Apr 2015	Mar 2016	$5,148	$2,046	$3,726
Niger	National Survey on Household Living Conditions and Agriculture 2014, Wave 2 Panel Data	Sep 2014	Mar 2015	$1,082	$526	$620
Nigeria	Nigerian Living Standards Survey 2018/19	Oct 2018	Sep 2019	$1,025	$622	$782
South Africa	General Household Survey 2018	Jan 2018	Dec 2018	n.a.	n.a.	n.a.
Sudan	National Household Budget & Poverty Survey 2014/2015	Jul 2014	June 2015	$1,635	$1,263	$1,394
Tanzania	Household Budget Survey 2017-2018	Nov 2017	Jan 2019	$797	$437	$564
Uganda	Uganda National Household Survey 2016/17	Jul 2016	June 2017	$716	$396	$486
Zambia	Zambia - Living Conditions Monitoring Survey VII 2015	Apr 2015	May 2015	$943	$255	$549

Source: World Bank staff analysis of household survey data.
Note: The South African survey did not ask enough questions about expenditures to enable calculation of the total household expenditure for each household and instead asked households which of the 10 expenditure categories they belonged to. n.a. = not available.

Annex 2: Supplementary Results for Urban and Rural Areas

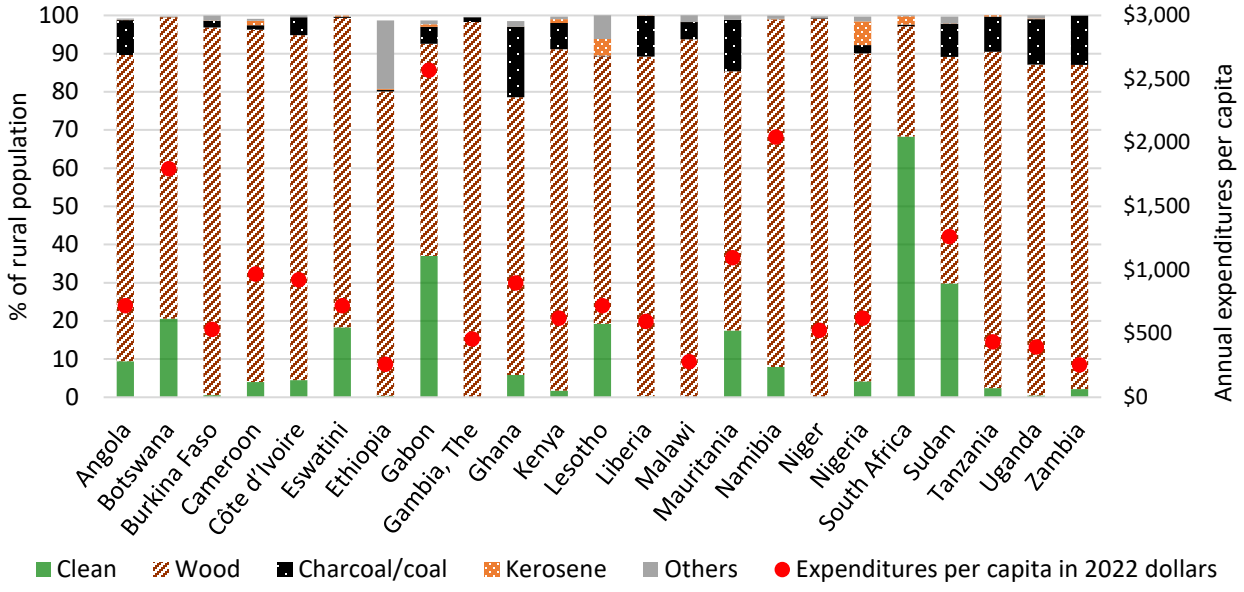
Figure A2.1 and Figure A2.2 reproduce Figure 2 for urban and rural areas, respectively. As expected, expenditures per capita are much higher in urban areas, and correspondingly a far greater proportion of urban residents uses clean cooking energy than rural residents.

Figure A2.1 Percentage of people living in households citing different primary energy sources for cooking and annual expenditures per capita in urban areas



Source: World Bank staff calculations using household survey data.
Note: Wood combines firewood and charcoal in Botswana. The South African survey did not ask enough questions to enable calculation of total household expenditures. Clean = LPG, electricity, biogas, and solar; others = mostly agricultural residues and dung.

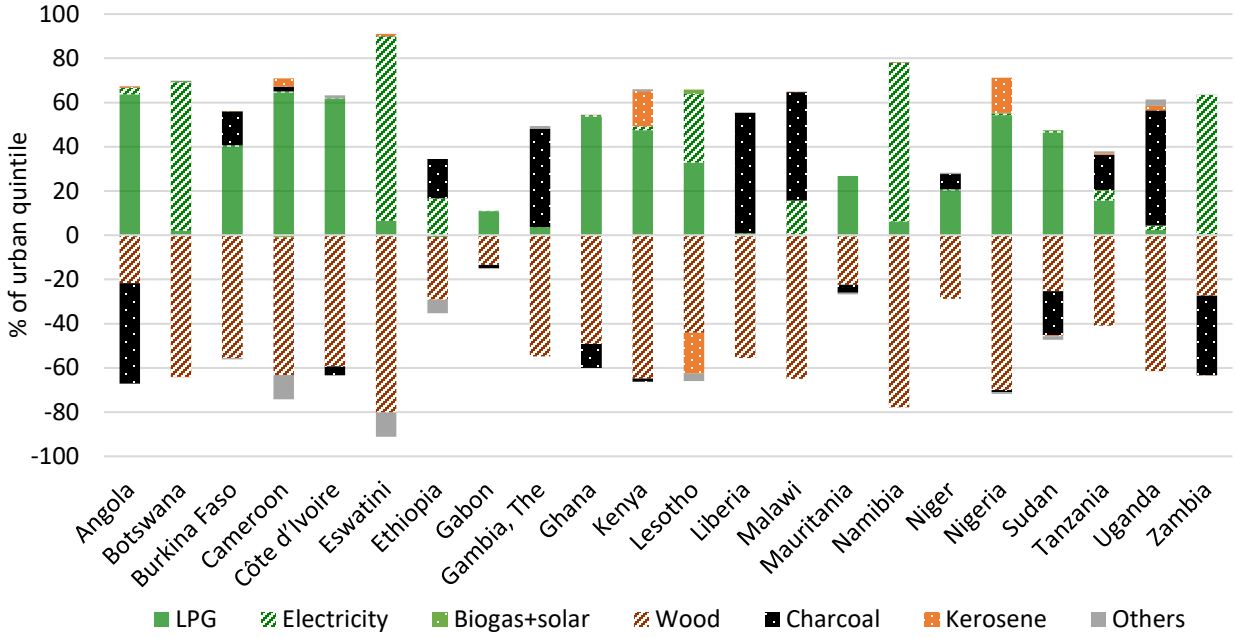
Figure A2.2 Percentage of people living in households citing different primary energy sources for cooking and annual expenditures per capita in rural areas



Source: World Bank staff calculations using household survey data.
Note: Wood combines firewood and charcoal in Botswana. The South African survey did not ask enough questions to enable calculation of total household expenditures. Clean = LPG, electricity, biogas, and solar; others = mostly agricultural residues and dung.

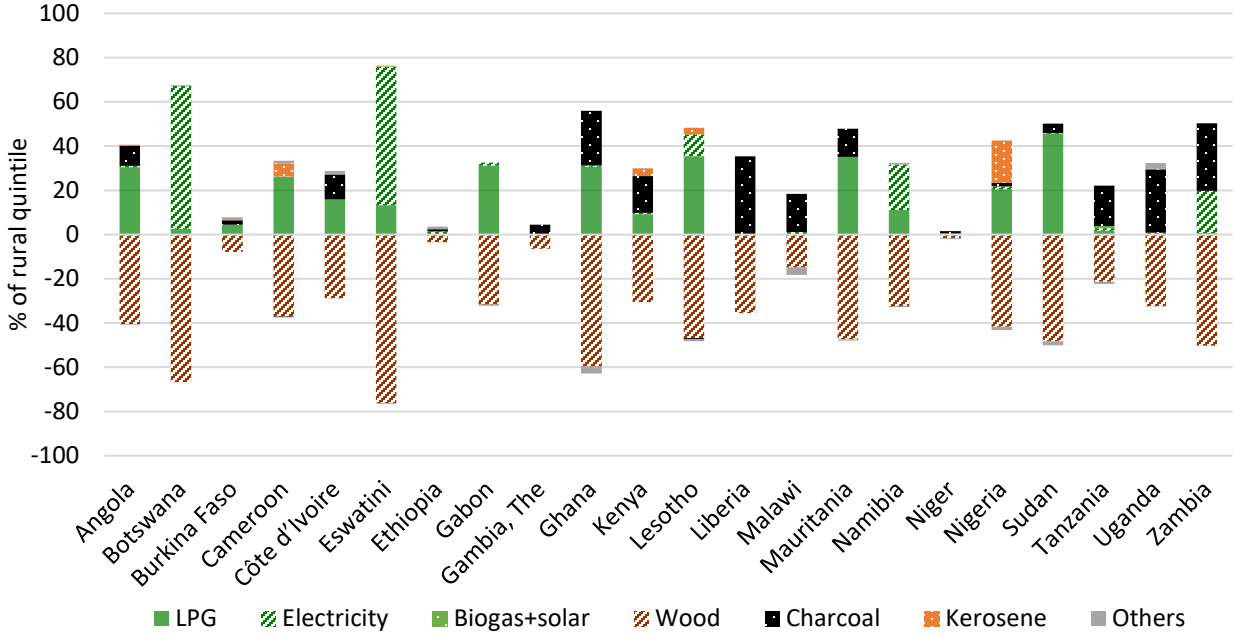
Figure A2.3 and Figure A2.4 show the same calculations as those for Figure 3. However, in interpreting the results, it is important to bear in mind that, unlike national statistics, the population in each quintile is not the same once people are disaggregated into urban and rural areas, and hence the differences show only qualitative trends. Importantly, for any energy source, the difference taking the national sample is not a weighted average of the differences in urban and rural areas.

Figure A2.3 Difference between the top and bottom quintile in the percentage of urban residents citing different forms of primary energy for cooking



Source: World Bank staff calculations using household survey data.
Note: For each energy category, the number shown is obtained by subtracting the share of the population in the bottom quintile from that in the top quintile. For example, 64% for LPG in Angola represents the difference between 90% of the top quintile and 26% of the bottom quintile citing LPG as the primary cooking fuel. Wood combines firewood and charcoal in Botswana. Others = mostly agricultural residues and dung.

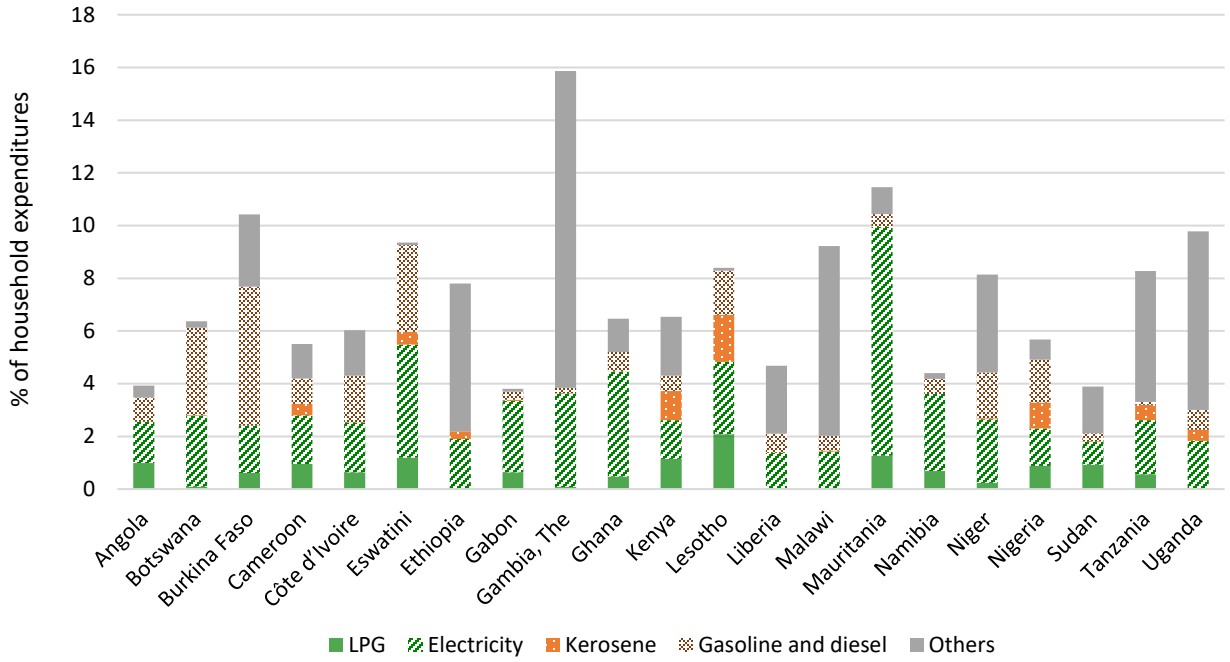
Figure A2.4 Difference between the top and bottom quintile in the percentage of rural residents citing different forms of primary energy for cooking



Source: World Bank staff calculations using household survey data.
Note: For each energy category, the number shown is obtained by subtracting the share of the population in the bottom quintile from that in the top quintile. For example, 31% for LPG in Angola represents the difference between 33% of the top quintile and 2.6% of the bottom quintile citing LPG as the primary cooking fuel. Wood combines firewood and charcoal in Botswana. Others = mostly agricultural residues and dung.

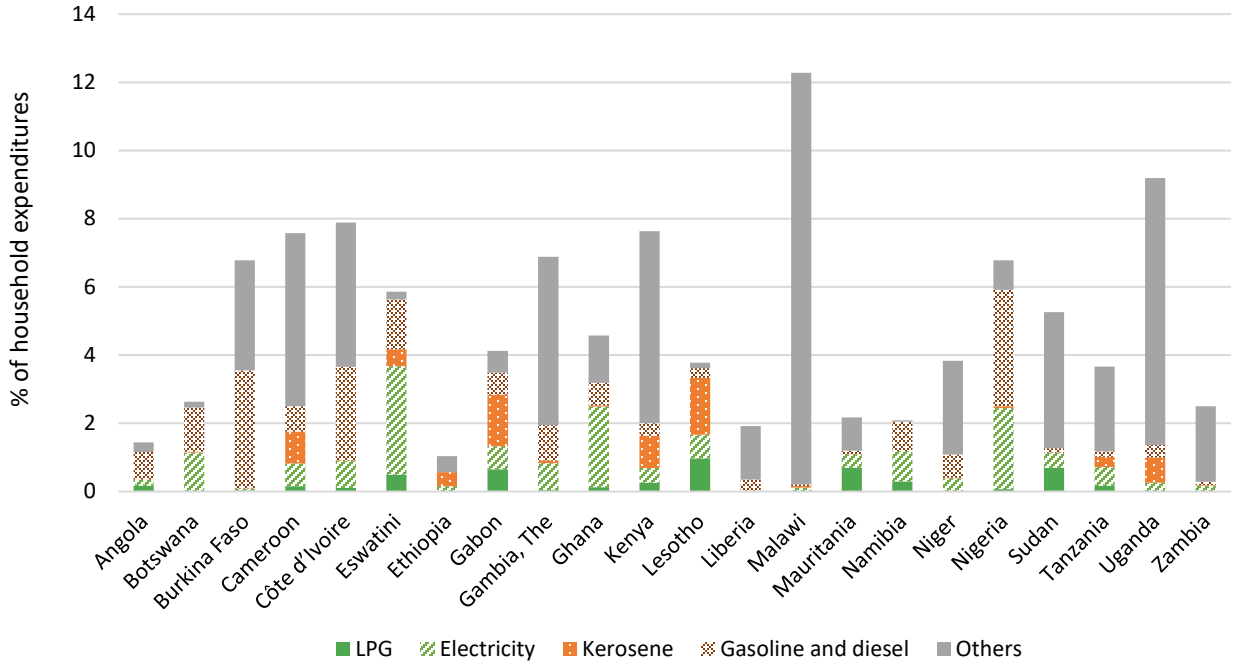
Figure A2.5 and Figure A2.6 show expenditure shares for different forms of household energy in urban and rural areas; the national statistics are presented in Figure 4. The expenditures on "others" should be interpreted with caution because they include imputed costs of freely acquired biomass, which is more readily available in rural areas. Urban Gambia and rural Malawi stand out for households spending more than 10 percent on "others," charcoal and wood in urban Gambia and wood in rural Malawi, with the latter likely to have captured a significant proportion of freely acquired wood.

Figure A2.5 Percentage of total household expenditures spent on different forms of energy by urban households



Source: World Bank staff calculations using household survey data.
Note: The expenditure shares are averaged across all households, including those reporting zero expenditures.

Figure A2.6 Percentage of total household expenditures spent on different forms of energy by rural households



Source: World Bank staff calculations using household survey data.
Note: The expenditure shares are averaged across all households, including those reporting zero expenditures.

Table A2.1 shows all possible combinations of energy sources used by households in Ghana. Ghana was selected for presentation in this paper because it had no fuel subsidies for households during the survey period and one-third of the population lived in households using LPG. In urban areas, 25 percent of households used only electricity or electricity in combination with LPG, against 8 percent in rural areas.

Table A2.1 Household Energy Use Patterns in Ghana

	Urban								Rural								National							
Rank	LPG	Elec	Kero	Char	Wood	Res	%	Cum %	LPG	Elec	Kero	Char	Wood	Res	%	Cum %	LPG	Elec	Kero	Char	Wood	Res	%	Cum %
1	1	1	0	1	0	0	30.0	30.0	0	1	0	0	1	0	24.5	24.5	0	1	0	1	0	0	20.9	20.9
2	0	1	0	1	0	0	26.6	56.7	0	0	0	0	1	0	22.5	47.0	1	1	0	1	0	0	20.3	41.2
3	1	1	0	0	0	0	18.2	74.8	0	1	0	1	0	0	13.6	60.6	0	1	0	0	1	0	12.4	53.5
4	0	1	0	0	0	0	6.5	81.3	0	1	0	1	1	0	10.0	70.6	1	1	0	0	0	0	12.1	65.6
5	0	1	0	1	1	0	4.8	86.1	1	1	0	1	0	0	7.8	78.4	0	0	0	0	1	0	10.6	76.2
6	0	0	0	1	0	0	3.1	89.2	1	1	0	0	0	0	4.3	82.7	0	1	0	1	1	0	7.1	83.3
7	0	1	0	0	1	0	2.9	92.1	0	1	0	0	0	0	3.3	85.9	0	1	0	0	0	0	5.1	88.4
8	0	0	0	0	1	0	1.3	93.4	0	0	0	1	1	0	2.8	88.7	0	0	0	1	0	0	2.8	91.1
9	1	1	0	1	1	0	1.2	94.6	0	0	0	1	0	0	2.4	91.0	0	0	0	1	1	0	1.8	92.9
10	0	0	0	1	1	0	1.0	95.6	1	1	0	1	1	0	1.4	92.4	1	1	0	1	1	0	1.3	94.2
11	1	0	0	1	0	0	0.8	96.4	1	1	0	0	1	0	1.3	93.7	1	1	0	0	1	0	0.8	94.9
12	0	1	1	1	0	0	0.7	97.1	0	0	0	0	0	0	1.0	94.7	0	0	0	0	0	0	0.7	95.7
13	1	1	1	1	0	0	0.6	97.6	0	1	1	1	1	0	1.0	95.7	0	1	1	1	1	0	0.5	96.2
14	0	0	0	0	0	0	0.5	98.2	0	0	1	0	1	0	0.8	96.5	1	0	0	1	0	0	0.5	96.7
15	0	0	1	1	0	0	0.5	98.7	0	0	1	1	1	0	0.6	97.0	0	1	1	1	0	0	0.5	97.2
16	1	1	0	0	1	0	0.3	99.0	0	0	0	0	0	1	0.5	97.6	0	0	1	0	1	0	0.4	97.6
17									0	1	0	0	0	1	0.3	97.9	1	1	1	1	0	0	0.4	98.0
18									0	1	1	0	1	0	0.3	98.2	0	0	1	1	0	0	0.4	98.3
19									1	0	0	0	1	0	0.3	98.4	0	0	1	1	1	0	0.3	98.7
20									1	0	0	0	0	0	0.2	98.7	0	0	0	0	0	1	0.2	98.9
21									0	1	1	1	0	0	0.2	98.9	1	0	0	0	0	0	0.2	99.1
22									0	0	1	1	0	0	0.2	99.1								

Source: World Bank staff calculations using the Ghana Living Standards Survey.

Note: There are 35 distinct combinations of energy sources in urban areas, 43 in rural areas, and 48 nationally. The combinations are listed in order of decreasing frequency for the first 99 percent of all households in each area. Other energy sources not captured in this table cited by respondents were sawdust, animal waste, and other fuels. Elec = electricity; kero = kerosene; char = charcoal; res = crop residues; % = percentage of households; cum % = cumulative percentage of households.

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