RUHR
ECONOMIC PAPERS

Julian Rose
Gunther Bensch
Anicet Munyehirwe
Jörg Peters

The Forgotten Coal: Charcoal Demand in Sub-Saharan Africa

rwi
#937

Imprint

Ruhr Economic Papers

Published by

RWI – Leibniz-Institut für Wirtschaftsforschung
Hohenzollernstr. 1-3, 45128 Essen, Germany

Ruhr-Universität Bochum (RUB), Department of Economics
Universitätsstr. 150, 44801 Bochum, Germany

Technische Universität Dortmund, Department of Economic and Social Sciences
Vogelpothsweg 87, 44227 Dortmund, Germany

Universität Duisburg-Essen, Department of Economics
Universitätsstr. 12, 45117 Essen, Germany

Ruhr Economic Papers #937

Responsible Editor: Manuel Frondel

ISSN 1864-4872 (online) – ISBN 978-3-96973-097-3

Ruhr Economic Papers #937

Julian Rose, Gunther Bensch, Anicet Munyehirwe, and Jörg Peters

The Forgotten Coal: Charcoal Demand in Sub-Saharan Africa

Bibliografische Informationen der Deutschen Nationalbibliothek

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at **http://dnb.dnb.de**

RWI is funded by the Federal Government and the federal state of North Rhine-Westphalia.

http://dx.doi.org/10.4419/96973097
ISSN 1864-4872 (online)
ISBN 978-3-96973-097-3

Julian Rose, Gunther Bensch, Anicet Munyehirwe, and Jörg Peters[1]

The Forgotten Coal: Charcoal Demand in Sub-Saharan Africa

Abstract

Charcoal is an important cooking fuel in urban Africa. In this paper, we estimate the current number of charcoal users and project trends for the coming decades. Charcoal production is often not effectively regulated, and it hence contributes to forest degradation. Moreover, charcoal has adverse health effects for its users. At the same time, charcoal constitutes an important income source in deprived rural areas, while the current alternative, gas, is a mostly imported fossil fuel. We find that 195 million people in sub-Saharan Africa rely on charcoal as their primary cooking fuel and gauge that another 200 million use charcoal as secondary fuel. Our scenarios suggest that clean cooking initiatives are outweighed by strong urban population growth and hence charcoal usage is expected to remain high over the coming decades. Policies should therefore target end-users, forest management, and regulation of charcoal production to enable sustainable production and use of charcoal.

JEL-Code: Q56, Q58, Q40, Q41, Q20, R11, O10

Keywords: Energy consumption; charcoal; Africa

January 2022

1 Julian Rose, RWI and University of Passau; Gunther Bensch, RWI; Anicet Munyehirwe, IB&C Rwanda; Jörg Peters, RWI and University of Passau. *- Peters and Rose acknowledge funding from the German Federal Ministry of Education and Research (BMBF), funding code 01LA1807A (DECADE). Anicet Munyehirwe is founder of Geni Green Solutions Ltd, a company that produces and distributes improved cookstoves and briquettes. We are grateful to Raavi Aggarwal for excellent comments and suggestions.* *– All correspondence to: Julian Rose, RWI, Hohnenzollernstr. 1/3, 45128 Essen, Germany, e-mail: julian.rose@rwi-essen.de*

1. Introduction

Traditional biomass accounts for almost 75 percent of the total energy use in sub-Saharan Africa (SSA, excluding South Africa), and it is mostly used for cooking. This share has barely changed over the past 25 years (IEA 2019). In rural areas, people use firewood, while charcoal is the dominant cooking fuel in urban areas because it is easier to transport. Charcoal consumption is thriving in SSA given the urbanization trends on the continent in the past two decades, which might be accelerated by advancing climate change (Castells-Quintana et al. 2021). IEA (2019) estimates an annual demand growth rate of four percent since 2000, and 60 percent of the world's charcoal is already produced in SSA. In this paper, we estimate the current number of charcoal users in SSA and trends for the coming decades, mostly based on the latest UN population projections and charcoal usage data from the Demographic and Health Surveys (DHS 2021).

Governments and international donors seek to support a transition away from biomass fuels and invest in promoting electricity and liquefied petroleum gas (LPG), guided by SDG 7.1 that postulates universal access to clean cooking by 2030. Yet, progress has been slow, with only 16 percent of households in SSA having access to clean cooking (IEA et al. 2021), partly due to a growing population. The negative consequences of Covid-19 will further hamper dissemination of clean fuels (IEA 2020; Pachauri et al. 2021).

The continued reliance on charcoal has its two sides: on the one hand, charcoal is problematic from an environmental perspective. In terms of forest degradation, charcoal is more harmful than firewood. First, because it is more wood-intense per calorific unit, second, because larger trunks and branches are used for its production, which degrades forests more than extensive firewood collection, and third because it is often extracted under unsustainable forest management regimes (FAO 2017; Bailis et al. 2015). Charcoal's forest degradation effect also contributes to climate change, according to estimates around one percent of global anthropogenic emissions (Bailis et al. 2015; FAO 2016). This amount is noteworthy even if minimal compared to other energy consumption emissions from industrialized and emerging countries – hard coal and lignite, for example, contributed 28 percent to global anthropogenic emissions in 2018 (Olivier and Peters 2019). Another adverse environmental effect of charcoal is air pollution, both at the production site and in the users' home (Bede-Ojimadu and Orisakew 2020; Das et al. 2017; Van Vliet et al. 2013).

On the other hand, charcoal is locally produced and creates a reliable income source and employment in otherwise often deprived rural areas (Khundi et al. 2011; Schure et al. 2014; Vollmer et al. 2017). According to the World Bank, charcoal creates between 200 and 350 local jobs for each TJ of consumed energy while electricity creates around 80 to 110, and LPG only 10 to 20 jobs (Putti et al. 2015).[1] The value of charcoal produced in SSA is estimated to be between USD 8 and 25 billion annually (World Bank 2011; UNEP 2014).[2] LPG, the main alternative for cooking, is a fossil fuel that is mostly imported and often subsidized, straining the trade balance and public budgets. Experiences in several countries underline that LPG subsidies can increase – mostly urban – uptake (Shankar et al. 2020). Yet, once subsidies end, households likely switch back to charcoal, as we later underpin with data from Senegal.

We estimate that currently almost 200 million people, or 18 percent of the population, in SSA are using charcoal as their main cooking fuel. This number is conservative in that the underlying DHS data does not consider households that use charcoal as a complementary fuel to LPG, nor does it account for commercial use in restaurants or small businesses. We use additional data sources that contain information on secondary fuel use from a sample of six countries to extrapolate continent-wide charcoal usage as secondary fuel. This estimate suggests – now with higher uncertainty – that about another 200 million people use charcoal as secondary cooking fuel. Another source of uncertainty is that secondary fuel usage can range from frequent use as a daily complement to gas to sporadic use for certain dishes or festivities.

Furthermore, we project two different primary user scenarios until 2040. In a base case scenario, we assume the share of fuel usage rates to be constant and that only population is changing. The

[1] Charcoal production often takes place informally, leaving small charcoal producers as the least empowered stakeholders in the sector (World Bank 2010). This might lead to exploitation by intermediaries and, eventually, the benefits of charcoal production might bypass local communities. For Malawi, Mwampamba et al. (2013) show that charcoal producers capture only 20 percent of the final value.

[2] Charcoal's value chain is in most countries local, and neither the import nor the export of charcoal plays an important role. Data on charcoal production and exports (FAO 2021) shows that exports in SSA account for 1.4% of the whole production of charcoal in 2020.

second scenario builds on the International Energy Agency's (IEA) "Stated Policies Scenario" (STEPS), accounting for SSA government's stated policies to increase usage rates of clean fuels (mainly electricity and LPG). The estimates from the scenarios underline the vital role that charcoal continues to play in the coming decades. In the base case scenario, the number of primary charcoal users increases by 260 percent, from 195 to over 380 million in 2040. Even in the STEPS scenario, the number of charcoal users remains on a high level of over 200 million users until 2035 before it decreases slowly to 165 million in 2040.

2. Data and Projections

Two variables are crucial for our analysis of current and future charcoal usage in SSA: demographic trends in rural and urban areas and access to clean fuels. Africa's growing population is increasingly moving to cities. This is important for projecting future charcoal demand because charcoal is the dominant fuel in urban areas in most SSA countries. This is mainly due to two factors: firewood cannot be widely collected in urban areas and transportation from rural source areas is less costly for charcoal than for firewood because of the lower weight per calorific value of charcoal. The alternatives, LPG and electricity, are subject to weak and intermittent supply chains and grids. Moreover, charcoal fits not only the cooking habits but also the budget constraints of the urban poor households due to the possibility of buying small quantities, whereas LPG has to be purchased in larger cylinders. Governments and international agencies address these barriers through LPG promotion policies, e.g., subsidization, which will likely reduce the number of charcoal users.

For our main projections of primary charcoal users, we employ three data sources. First, we use the most recent Demographic and Health Surveys (DHS) for information on the current primary fuel mix for the 32 available SSA countries (DHS 2021).[3] For the remaining ten assessed countries

[3] Timing of DHS data collections vary across countries. Table A1 lists all countries with the corresponding year of the data collection.

not covered by the DHS, we use data of best-matching neighbours to approximate fuel choices.[4] The data provides primary fuel shares that are representative of rural and urban areas.

The second data source are the 2018 UN population projections with their population trends for urban and rural areas (UN 2018). The third data source is the Stated Policies Scenario (STEPS) from IEA, deriving future fuel mixes until 2040 based on policy frameworks announced by governments and international stakeholders. The IEA assumes the following clean fuel shares in STEPS: 17.1 percent (2020), 21.8 percent (2025), 30 percent (2030), and 65 and 40 percent for urban and rural households, respectively (2040). We compare these policy ambitions with a simple base case scenario, in which we assume that only population changes over time while – pessimistically – the fuel choices of households proportionally remain the same. Both scenarios go from 2020 to 2040 given that IEA's STEPS projections end in 2040.

DHS only elicits the use of charcoal as the primary cooking energy source. For our additional analysis of secondary charcoal usage, we employ another set of data sources. Here, we first use secondary cooking fuel usage data from the nationally representative Living Standards Measurement Studies (LSMS), available for Uganda, Niger, Tanzania, and Mali (LSMS 2021). The data only allows for detecting secondary fuel use but does not provide estimates on the quantity of charcoal consumed. Second, we use primary data that we collected in major cities in Senegal and Burkina Faso (Bensch and Peters 2013; Bensch et al. 2015). Third, World Bank's Energy Sector Management Assistance Program (ESMAP) conducted specific energy use surveys in recent years, the so-called *Multi-Tier Framework (MTF) Surveys for Measuring Energy Access*. Like DHS, the MTF surveys are nationally representative cross-sections, for which data is available from eight SSA countries so far. While none of the surveys can be used to distinguish primary and secondary fuel usage, the data collections in Ethiopia, Kenya, Rwanda, and Zambia at least include information on any charcoal usage for cooking, i.e., an estimate of aggregate primary and secondary charcoal

[4] The ten countries in SSA not covered by the DHS are Botswana, Central African Republic, Equatorial Guinea, Eritrea, Guinea-Bissau, Mauritania, Somalia, South Africa, Sudan, and Swaziland. We furthermore abstain from applying this approach to the six smallest, mostly island countries in SSA, namely Comoros, Cabo Verde, Djibouti, Mauritius, Sao Tome & Principe, and Seychelles.

usage. Lastly, we use data from a study on the cooking sector in Kenya by the Kenyan Government (Government of Kenya 2019).

3. Results

We first estimate the current number of charcoal users in SSA by combining the UN population data with the fuel shares obtained from DHS. We estimate that 195 million people currently use charcoal as primary cooking energy.

Figure 1 depicts the share of charcoal users by country in rural and urban areas in 2020. Moreover, it shows the total number of charcoal users in each country. The figure underlines the importance of charcoal in urban areas with usage rates above 50 percent in 14 of the 42 assessed countries. For entire SSA, 77 percent of users are urban residents. Regarding the absolute number of charcoal users, the Democratic Republic of Congo is the country with the highest number (29 million), followed by Tanzania, Sudan and South Sudan[5], Ethiopia, Nigeria, and Uganda (between 12 and 18 million users). Low usage rates can have different reasons. In very poor countries, like Niger or Central African Republic, it is because of the prominence of firewood, while in some better-off countries, especially in Southern Africa, LPG or electricity have replaced charcoal.

Figure 2 presents the results for the projected scenarios for the future development of primary charcoal users. In the base case scenario, assuming constant fuel choices in rural and urban areas, the number of charcoal users increases proportionally to urbanization rates (Panel A). By 2040, over 380 million people would rely on charcoal as their primary cooking energy, representing an increase of almost 200 percent compared to 2020.

Figure 2 emphasizes the role of urbanization for charcoal usage: the nationwide share of charcoal users increases, even though we hold the shares of urban and rural charcoal users constant in the base case scenario. The number of charcoal users will also increase in the STEPS scenario, to over 200 million by 2035 before it slowly decreases to 164 million in 2040 (Panel B). Note that – despite the decrease in the share of charcoal users in the STEPS scenario – the absolute number still increases until 2035 because population growth is outpacing the increase in clean fuel usage. In

[5] DHS data is not available for Sudan and South Sudan separately.

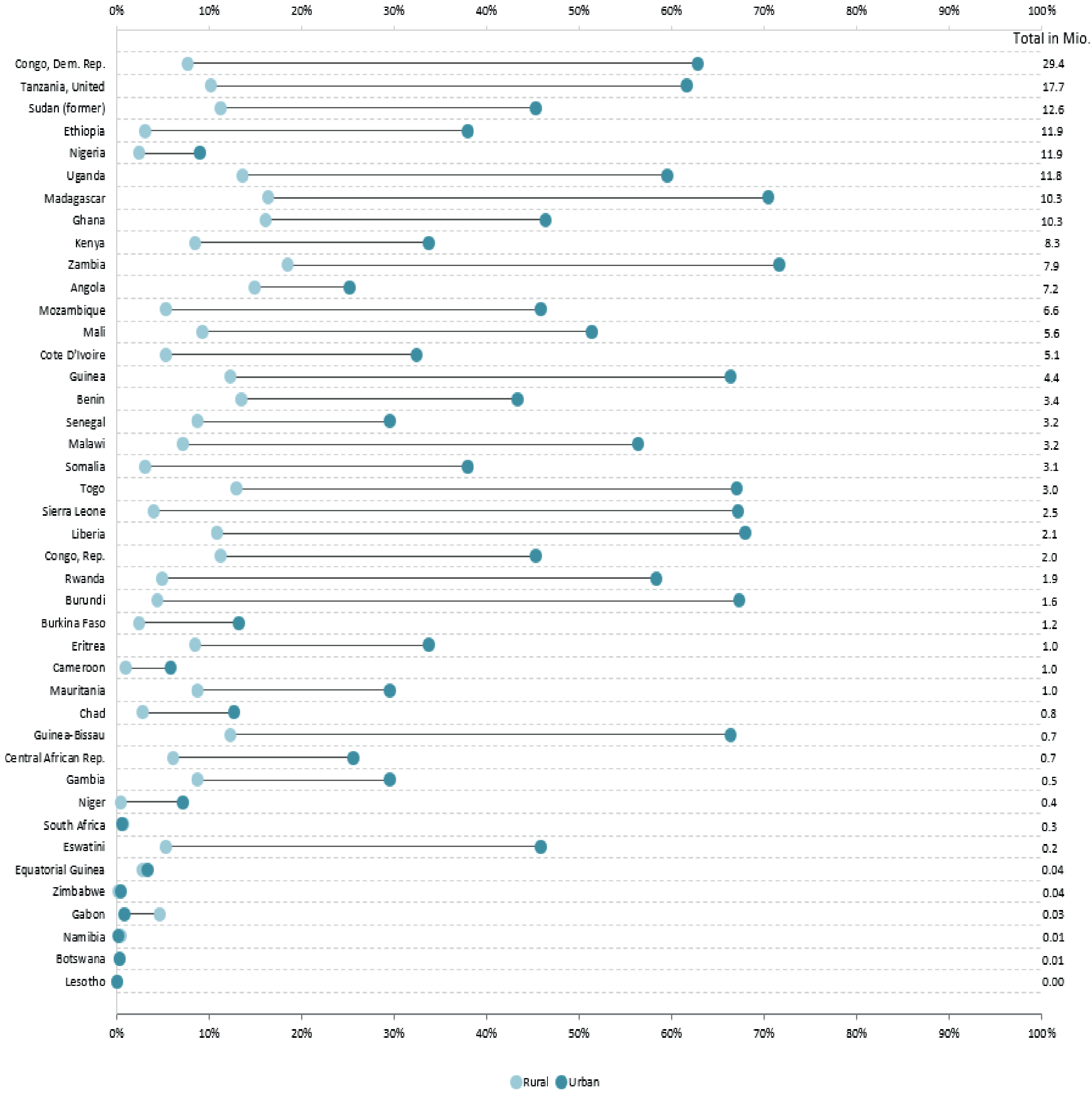
this scenario, the number of clean fuel users has to more than triple until 2035 (from roughly 190 million to over 600 million) to achieve the reduction in the number of charcoal users. Yet, recent projections by Pachauri et al. (2021) cast doubt on the likelihood of such a significant increase in clean cooking. The STEPS scenario is hence a lower bound of future charcoal usage.

Hitherto, we have looked at charcoal as primary cooking fuel and excluded commercial use. Hence, the estimates are probably conservative because fuel stacking is widespread in SSA. Many users of LPG (or in a few countries electricity) still use charcoal as the secondary fuel. Secondary fuel use could imply usage for festivities, but also that it is used frequently, for example for side dishes or during certain periods of the year (see Bensch and Peters 2013 for the case of urban Senegal).

We now explore several additional data sources to gauge the relevance of charcoal as secondary cooking fuel. Figure 3 summarizes the secondary cooking fuel usage rates for urban (Panel A) and rural areas (Panel B). For Mali we find that charcoal is widely used as secondary fuel (50 percent of households) in both urban and rural areas. Kenya is another country for which we find high usage rates of charcoal as secondary fuel in urban and rural areas. Secondary usage is below 20 percent for the remaining countries, but still varies substantially. We observe similar patterns when comparing primary usage from the DHS data with any charcoal usage from the available MTF data, for which the distinction between primary and secondary fuel use cannot be made (see Figure A 1 in the appendix).

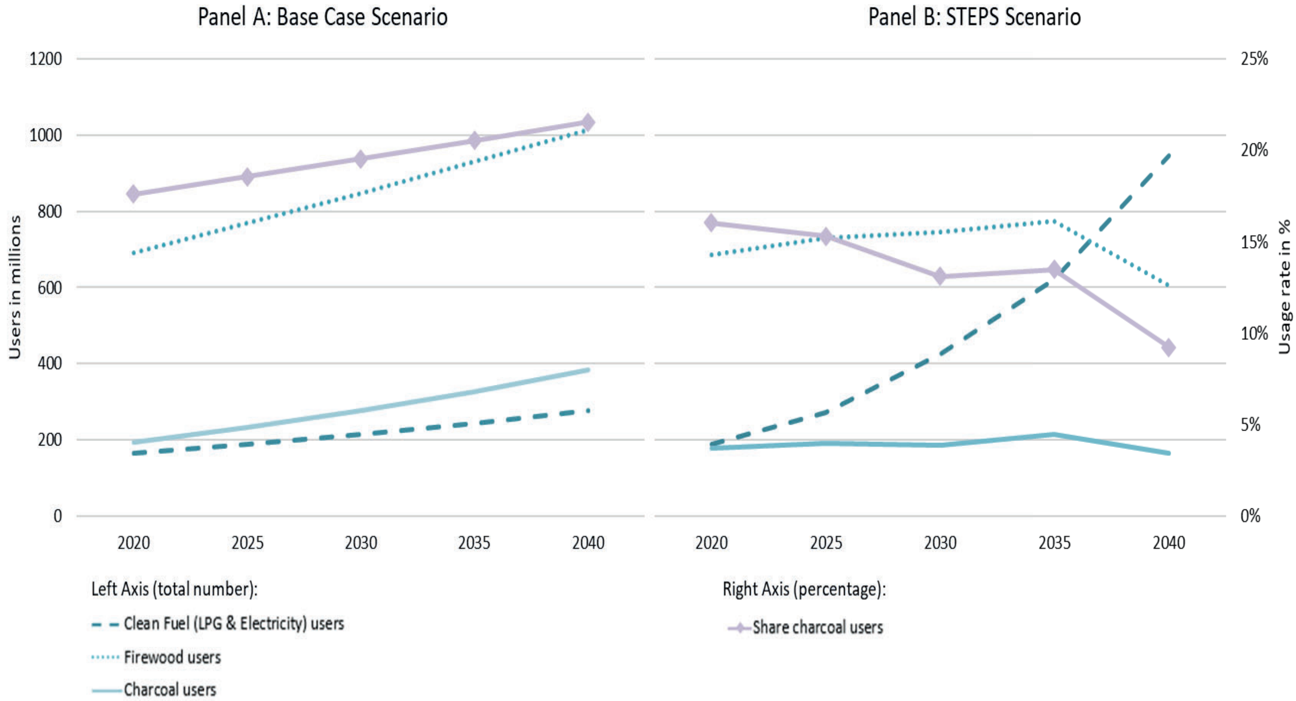
Most of the primary usage rates found in the LSMS data (Mali, Niger, Tanzania, and Uganda) are quite consistent with the DHS data. The relation between primary and secondary usage, however, differs drastically across countries, both when compared within the datasets and with the DHS data. Several additional factors make the comparison between the DHS data and the other datasets difficult, including differences in the seasonal timing of the surveys, in the sampling, and measurement. Nevertheless, it seems fair to conclude from this data that secondary charcoal fuel use amounts to around 20 percent in urban areas and slightly below that in rural areas, which would add another roughly 100 million secondary charcoal users in rural and urban areas each, thus about the same number as primary charcoal users. The extent of charcoal usage among these households is, however, unclear.

Figure 1: Number of charcoal users and their shares in urban and rural areas (2020)



Note: The left part of the figure shows the share of charcoal users in urban and rural areas in each country. The numbers on the right show the total number of charcoal users in each country. Calculations are based on DHS and UN Population data.

Figure 2: Scenario results on charcoal users in SSA

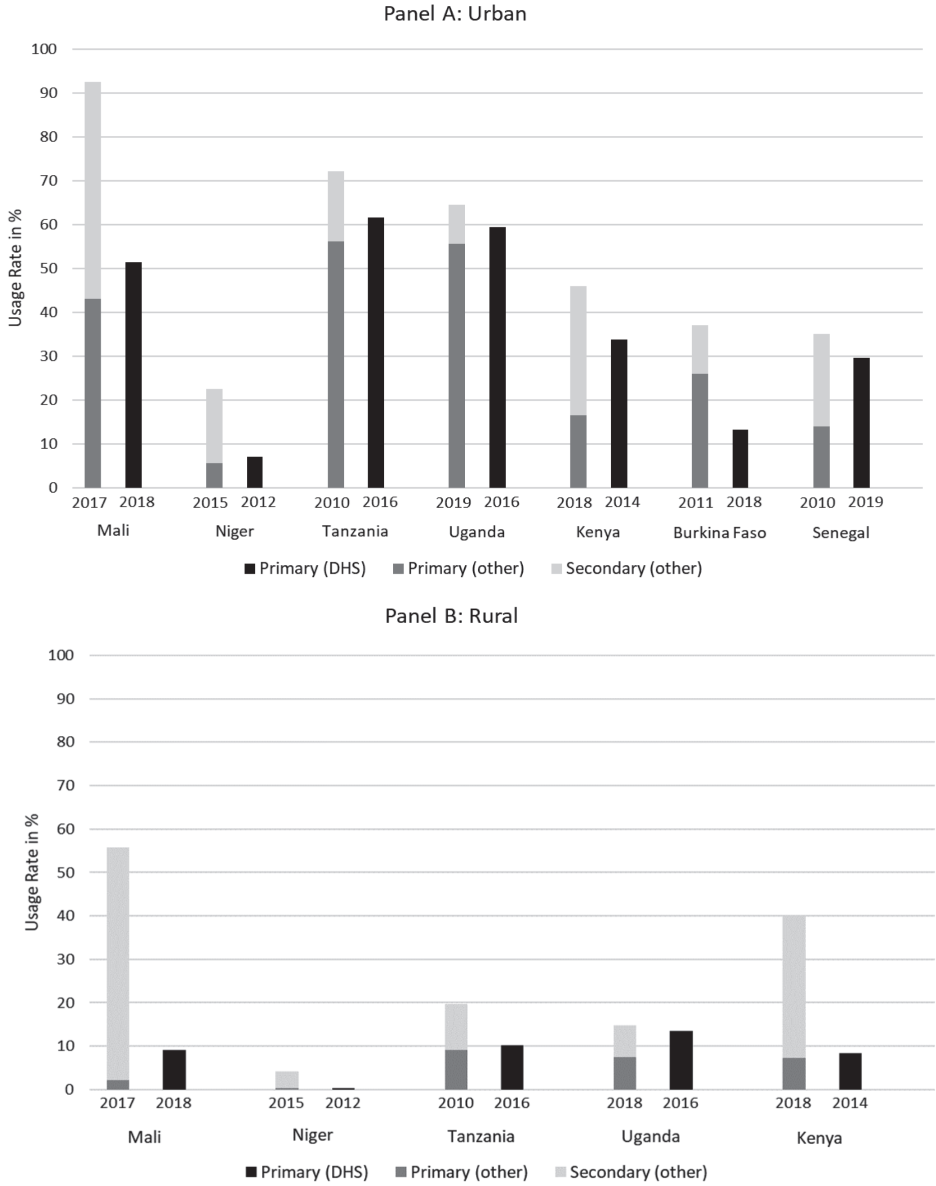


Note: Panel A presents the results for the base case scenario from 2020 until 2040. Panel B presents the results for the Stated Policies Scenario (STEPS) from the IEA.

Most of the primary usage rates found in the LSMS data (Mali, Niger, Tanzania, and Uganda) are quite consistent with the DHS data. The relation between primary and secondary usage, however, differs drastically across countries, both when compared within the datasets and with the DHS data. Several additional factors make the comparison between the DHS data and the other datasets difficult, including differences in the seasonal timing of the surveys, in the sampling, and measurement. Nevertheless, it seems fair to conclude from this data that secondary charcoal fuel use amounts to around 20 percent in urban areas and slightly below that in rural areas, which would add another roughly 100 million secondary charcoal users in rural and urban areas each, thus about the same number as primary charcoal users. The extent of charcoal usage among these households is, however, unclear.

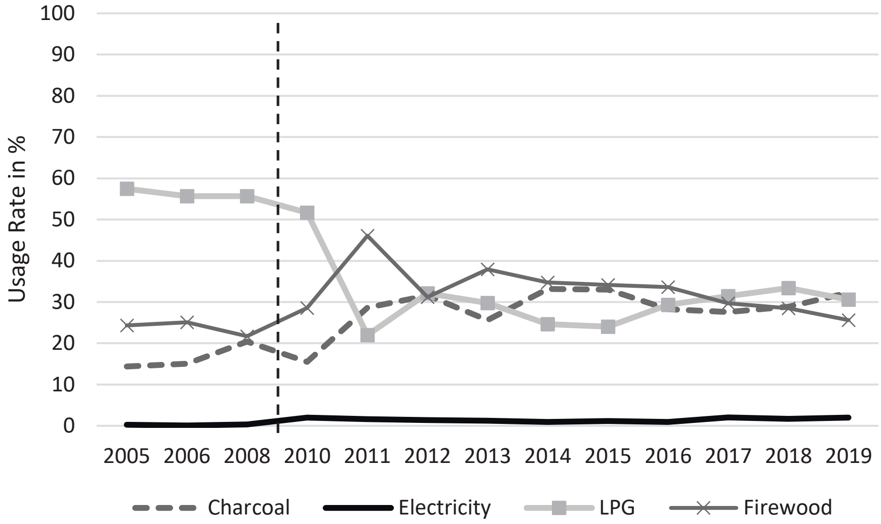
Our scenarios are also sensitive to additional policy instruments in the future. Clean fuel policies may be stepped up, but also subsidy removals or carbon levies are imaginable. The latter would likely increase charcoal users compared to the numbers projected in our scenarios. Carbon pricing policy instruments, for example, would be more likely to mainly hit LPG since the carbon footprint of charcoal is hard to ascertain and because the charcoal production sector is very informal. Figure 4 shows the LPG and charcoal usage responses among urban Senegalese households after a decade-long LPG subsidy was removed in 2009. The figure underlines that the LPG usage rate dropped sharply after the subsidy was removed while charcoal (and firewood) usage increased.

Figure 3: Estimates of charcoal usage as secondary cooking fuel



Note: For Niger, Tanzania, Uganda, and Mali we use LSMS data (LSMS 2021). For Kenya we report numbers from an official report (Republic of Kenya 2019). The data for urban Burkina Faso is from Bensch et al. (2015) and for urban Senegal from Bensch and Peters (2013).

Figure 4: Primary cooking fuel choices in urban Senegal before and after subsidy removal



Note: This figure presents the share of primary urban cooking fuels from 2005 to 2019 in Senegal. The dashed line indicates the removal of the LPG subsidies. Own calculations based on DHS.

4. Conclusion

The scenarios presented in this article underline that charcoal will very likely remain an important fuel in SSA in the coming decades. The number of charcoal users will probably remain high until 2040, even when governments implement all policy intentions planned to date. Moreover, charcoal plays an important economic role in rural areas, creating jobs and income in otherwise deprived areas (see Putti et al. 2015; Schure et al. 2014; Vollmer et al. 2017). Taken together, replacing charcoal entirely is not only economically but politically challenging for local governments. Attempts to ban charcoal without rapidly ramping up alternatives (i.e., subsidize LPG) do not seem to be warranted.

We therefore call for a stronger inclusion of alternative strategy elements that lead to a more sustainable charcoal sector, notably effective charcoal regulation and investments into more efficient production and user technologies. Effective regulation includes forest management by establishing rules for sustainable charcoal production, such as cutting techniques and rotating harvest areas to allow forests to recover, as well as investments into afforestation. This approach emphasizes that charcoal can be a renewable fuel if the wood is harvested sustainably. Moreover, effective regulation should replace informal with formal production without excluding small producers. Thereby the government can also create revenue from taxes which could be re-invested into forest management.

Complementarily, governments and international donors should invest in more efficient production technologies. In particular, improved kilns for the carbonization process promise significant efficiency gains by reducing the wood needed. Modern kilns achieve a conversion efficiency of up to 40 percent, whereas traditional earth-mound kilns have an efficiency range of 9 to 30 percent leading to substantial wood requirements (FAO 2017). At the other end of the charcoal value chain, end users can economize charcoal by using improved cookstoves that burn charcoal more efficiently, which is also a promising pathway for carbon finance (Bensch et al. 2021, 2015; Bensch and Peters 2013; Berkouwer and Dean 2021; Gebreegziabher et al. 2018).

These charcoal policies must be seen as complementary to the long-term transition to clean cooking. Scenarios other than the predicted here are possible. For example, IEA's Net-Zero – a policy scenario that outlines a potential trajectory to net-zero carbon emissions by 2050 – assumes traditional biofuels to be replaced rapidly by LPG, biogas, electricity, and carbon-neutral biofuels (IEA 2021). This is a desirable scenario, which would yet require governmental investment many times greater than foreseen under current policies. We believe it is likelier that charcoal usage remains high over the coming decades. This requires resolute policy action to make charcoal an environmentally sustainable fuel, maintain its economic importance for producing regions, and cushion the adverse health effects at the end user level.

References

Bailis, R., Drigo, R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional woodfuels. *Nature Climate Change, 5*(3), 266-272.

Bede-Ojimadu, O., & Orisakwe, O. E. (2020). Exposure to wood smoke and associated health effects in sub-Saharan Africa: A systematic review. *Annals of global health*, *86*(1).

Bensch, G., & Peters, J. (2013). Alleviating deforestation pressures? Impacts of improved stove dissemination on charcoal consumption in urban Senegal. *Land Economics*, *89*(4), 676-698.

Bensch, G., Grimm, M., & Peters, J. (2015). Why Do Households Forego High Returns from Technology Adoption? Evidence from Improved Cooking Stoves in Burkina Faso. *Journal of Economic Behavior and Organization 116*, 187-205. DOI: 10.1016/j.jebo.2015.04.023

Bensch, G., Jeuland, M., & Peters, J. (2021). Efficient biomass cooking in Africa for climate change mitigation and development. *One Earth*, *4*(6), 879-890.

Berkouwer, S. B., & Dean, J. T. (2021). Credit, attention, and externalities in the adoption of energy efficient technologies by low-income households. *Unpublished manuscript, University of Pennsylvania, Philadelphia, PA*.

Castells-Quintana, D., Krause, M., & McDermott, T. K. (2021). The urbanising force of global warming: the role of climate change in the spatial distribution of population. *Journal of Economic Geography*, *21*(4), 531-556.

Das, I., Jagger, P., & Yeatts, K. (2017). Biomass cooking fuels and health outcomes for women in Malawi. *Ecohealth*, *14*(1), 7-19.

DHS, Demographic and Health Surveys (2021). Available Datasets, <https://dhsprogram.com/data/available-datasets.cfm>.

FAO, Food and Agriculture Organization of the United Nations (2016). *Forestry for a low-carbon future: integrating forests and wood products in climate change strategies.* FAO Forestry Paper No. 177. Rome, Food and Agriculture Organization of the United Nations.

FAO, Food and Agriculture Organization of the United Nations (2017). *The charcoal transition: greening the charcoal value chain to mitigate climate change and improve local livelihoods*, by J. van Dam. Rome, Food and Agriculture Organization of the United Nations.

FAO, Food and Agriculture Organization of the United Nations (2021). FAOSTAT statistical database. Rome, Food and Agriculture Organization of the United Nations.

Gebreegziabher, Z., Beyene, A. D., Bluffstone, R., Martinsson, P., Mekonnen, A., & Toman, M. A. (2018). Fuel savings, cooking time and user satisfaction with improved biomass cookstoves: Evidence from controlled cooking tests in Ethiopia. *Resource and Energy Economics*, *52*, 173-185.

Government of Kenya (2019). *Kenya Household Cooking Sector Study*. https://eedadvisory.com/wp-content/uploads/2020/09/MoE-2019-Kenya-Cooking-Sector-Study-compressed.pdf

IEA, International Energy Agency (2019). *World Energy Outlook 2019*. Paris, OECD Publishing.

IEA, International Energy Agency (2020). *SDG7: Data and Projections*, https://www.iea.org/reports/sdg7-data-and-projections.

IEA, International Energy Agency (2021). *Net Zero by 2050 – A Roadmap for the Global Energy Sector*. Paris, OECD Publishing.

IEA, IRENA, UNSD, World Bank, WHO (2021). *Tracking SDG 7: The Energy Progress Report*. Washington DC, World Bank.

Khundi, F., Jagger, P., Shively, G., & Sserunkuuma, D. (2011). Income, poverty and charcoal production in Uganda. *Forest Policy and Economics*, *13*(3), 199-205.

LSMS, Living Standards Measurement Study (2021). Available Datasets, https://microdata.worldbank.org/index.php/catalog/lsms.

Mwampamba, T. H., Owen, M., & Pigaht, M. (2013). Opportunities, challenges and way forward for the charcoal briquette industry in Sub-Saharan Africa. *Energy for Sustainable Development, 17(2)*, 158-170.

Pachauri, S., Poblete-Cazenave, M., Aktas, A., & Gidden, M. J. (2021). Access to clean cooking services in energy and emission scenarios after COVID-19. *Nature Energy 6*, 1067-1076.

Putti, V. R., Tsan, M., Mehta, S., & Kammila, S. (2015). The state of the global clean and improved cooking sector. Available at: https://openknowledge.worldbank.org/handle/10986/21878

Olivier, J. G. J. & Peters, J. A. H. W. (2019). Trends in global CO2 and total greenhouse gas emissions: 2019 report. The Hague, PBL Netherlands Environmental Assessment Agency.

Schure, J., Levang, P., & Wiersum, K. F. (2014). Producing woodfuel for urban centers in the Democratic Republic of Congo: a path out of poverty for rural households? *World Development*, *64*, S80-S90.

Shankar, A. V., Quinn, A. K., Dickinson, K. L., Williams, K. N., Masera, O., Charron, D., ... & Rosenthal, J. P. (2020). Everybody stacks: Lessons from household energy case studies to inform design principles for clean energy transitions. *Energy Policy*, *141*, 111468.

UN, United Nations (2018). *World Urbanization Prospects: The 2018 Revision,* Online Edition.

UNEP, United Nations Environment Program (2014). *Illegal trade in wildlife: the environmental, social and economic consequences for sustainable development: Information note by the secretariat*. Nairobi, UNEP.

Van Vliet, E. D., Asante, K., Jack, D. W., Kinney, P. L., Whyatt, R. M., Chillrud, S. N., ... & Owusu-Agyei, S. (2013). Personal exposures to fine particulate matter and black carbon in households cooking with biomass fuels in rural Ghana. *Environmental Research*, *127*, 40-48.

Vollmer, F., Zorrilla-Miras, P., Baumert, S., Luz, A. C., Woollen, E., Grundy, I., ... & Patenaude, G. (2017). Charcoal income as a means to a valuable end: Scope and limitations of income from rural charcoal production to alleviate acute multidimensional poverty in Mabalane district, southern Mozambique. *World Development Perspectives*, *7*, 43-60.

World Bank (2010). *Enabling reforms: a stakeholder-based analysis of the political economy of Tanzania's charcoal sector and the poverty and social impacts of proposed reforms*. Word Bank, Washington, DC.

World Bank (2011). *Wood-Based Biomass Energy Development for Sub-Saharan Africa: Issues and Approaches. Energy Sector Management Assistance Program (ESMAP).* World Bank, Washington, DC.

Appendix

Figure A 1: Charcoal usage rates according to MTF and DHS data

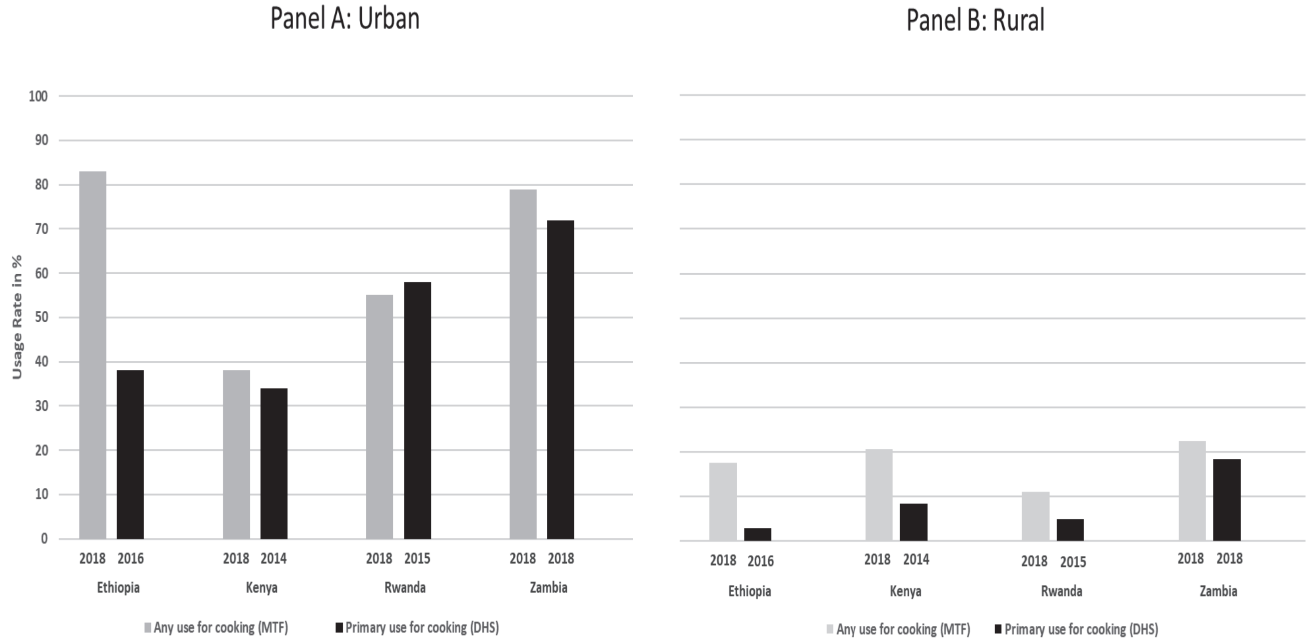


Table A 1: Timinig of DHS data

Country	Data source	Year
Angola	DHS	2015/16
Benin	DHS	2017/18
Botswana	Nearest Neighbours (Angola, Zambia)	
Burkina Faso	DHS	2017/18
Burundi	DHS	2016/17
Cameroon	DHS	2018
Central African Rep.	Nearest Neighbours (Cameroon, Dem. Rep. Congo)	
Chad	DHS	2014/15
Congo, Dem. Rep.	DHS	2013/14
Congo, Rep.	DHS	2011/12
Cote D'Ivoire	DHS	2011/12
Equatorial Guinea	Nearest Neighbours (Cameroon, Gabon)	
Eritrea	Nearest Neighbour (Kenya)	
Ethiopia	DHS	2016
Gabon	DHS	2012
Gambia	Nearest Neighbour (Senegal)	
Ghana	DHS	2017
Guinea	DHS	2018
Guinea-Bissau	Nearest Neighbour (Giunea)	
Kenya	DHS	2014
Lesotho	DHS	2014
Liberia	DHS	2019/20
Madagascar	DHS	2016
Malawi	DHS	2017
Mali	DHS	2018
Mauritania	Nearest Neighbour (Senegal)	
Mozambique	DHS	2018
Namibia	DHS	2013
Niger	DHS	2012
Nigeria	DHS	2018
Rwanda	DHS	2014/15

Senegal	DHS	2019*
Sierra Leone	DHS	2019
Somalia	Nearest Neighbour (Ethiopia)	
South Africa	DHS	2003/04
Sudan (former)	Nearest Neighbours (Dem. Rep. Congo)	
Swaziland	DHS	2006/07
Tanzania, United	DHS	2017
Togo	DHS	2017
Uganda	DHS	2016
Zambia	DHS	2018
Zimbabwe	DHS	2015

Note: The table indicates for each country the source and the year of the data collection. Source: DHS (2021).