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CHARCOAL IN THE MODERN COOKING TRANSITION

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ABBREVIATIONS

ARI	acute respiratory infection
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CPA	charcoal producer association
FAO	Food and Agriculture Organization of the United Nations
g	gramme
GACC	Global Alliance for Clean Cookstoves
GBEP	Global Bioenergy Partnership
GHG	greenhouse gas
HAP	household air pollution
ISO	International Organization for Standardization
KES	Kenyan shilling
kg	kilogramme
LPG	liquefied petroleum gas
µg	microgramme
m^3	cubic metre
MECS	modern energy cooking services
Mt	million tonnes
NGO	nongovernmental organisation
NMHC	non-methane hydrocarbon
$PM_{2.5}$	particulate matter of less than 2.5 microns
RBF	results-based finance
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SDG	Sustainable Development Goal
SSA	Sub-Saharan Africa
t/ha	tonne/hectare
UN	United Nations
USD	United States dollar
WHO	World Health Organization

EXECUTIVE SUMMARY

Sustainable Development Goal 7 (SDG7) calls for universal access to modern cooking energy; however, subsequent reporting on the Goal has consistently revealed slow progress in achieving access to clean cooking, with the latest reports finding that gains in access are outpaced by population growth, particularly in Sub-Saharan Africa (SSA). The political momentum that has been generated for clean cooking since 2015 and the unprecedented investments that have been mobilised towards it are far from sufficient to fully transition the population that is dependent on biomass to using modern cooking fuels. To date, 2.1 billion people, the majority of them in SSA, remain reliant on traditional cooking fuels in the forms of charcoal and firewood.

Most of Africa – the continent with the highest deficit in clean cooking access – is experiencing increasing demand for charcoal. Population growth and high urbanisation rates are expected to continue to intensify this demand. In addition, the adoption of clean cooking fuels like liquefied petroleum gas (LPG) is unlikely to keep pace with the growth in the demand for charcoal: most of the population in SSA cannot afford to make a clean fuel transition, while an even larger share will continue using charcoal as a secondary fuel. Indeed, missing from most clean cooking debates is charcoal's important role in securing cooking energy access – now and in the future – for a large share of SSA's population, for whom the transition to LPG, electricity and other modern fuels remains a significant challenge.

This dependence on charcoal, however, comes at a high environmental cost. It also raises important questions about the policy direction that should be taken regarding charcoal's production and use. Given the expected continued dependence on charcoal for cooking energy, innovations and investments that contribute to the modernisation of its production and use are urgently needed.

When the entire scope of benefits and impacts is considered, including energy access and energy security, the transition pathway for charcoal that emerges is one that entails its sustainable production and use. The following measures are needed to achieve this type of transition:

A change in the perception of charcoal as a fuel that households in SSA will transition away from entirely (*i.e.* a transition fuel) is needed. There is limited evidence to suggest that its use is decreasing in a manner that would result in its phase out by 2050 or even beyond that. Acknowledging this reality can in turn lead to better planning for a charcoal-based future. Evidence shows that charcoal and fuelwood will continue to sustain cooking energy needs in SSA for some time to come. The most likely transition that is consistent with past evidence sees fuelwood users switching to charcoal, which would only worsen the energy access situation in the absence of robust and realistic charcoal planning.

A just transition lens is needed in viewing the charcoal transition. From this perspective, modernised charcoal seems to be a promising and scalable solution for tackling the energy access challenge in Africa while preserving the livelihoods of millions of people that are dependent on the charcoal value chain. The co-benefits would include preserving the countries' limited foreign exchange. If the objective of charcoal policy shifts from encouraging a mass transition away from it (which has largely failed) to perceiving it as a means of ensuring an immediate and secure form of cooking energy for SSA's population, notable co-benefits such as forest conservation and climate protection would inherently follow.

The supply side of charcoal has thus far been neglected, yet it offers significant opportunities for improvement. Most interventions focus on consumption levels where both health and climate impacts are fewer, rather than production levels where there are significant environmental impacts. Measures such as efficient charcoal production and extraction, developing and supporting the adoption of efficient charcoal kilns, and fostering sustainable feedstocks for charcoal should be undertaken as primary interventions, alongside complementary end-use measures like the promotion of efficient cookstoves.

Technical interventions need to be accompanied by awareness campaigns, end-user training, supportive policies and regulations, and financing. Policies and regulations should shift towards supporting the adoption of improvements (in production, processing and utilisation) and away from punishing the production and transport of charcoal, given the ineffectiveness of such measures in the long run.

A product-centric approach[1] may be needed to transform perceptions of charcoal from an unsustainable, traditional, dirty, poor people's fuel to a modern cooking energy that can tackle the energy access challenge in Africa. This report proposes a new form of cooking energy, "modern charcoal", whose only resemblance to traditional charcoal is in the final product. Such a fuel would be as distinctive from traditional charcoal as any other modern fuel is: in its production, harvesting, processing, transport and use. Such a reframing of charcoal could be what is needed to overcome the established and deeply rooted misconceptions about charcoal.

Moving forward with the proposed recommendations requires resolving the controversies surrounding charcoal's impacts. The analysis in this report finds that charcoal in its current form of use has significantly negative environmental impacts, including forest degradation and greenhouse gas (GHG) emissions. Meanwhile, charcoal's negative health impacts appear to be overstated because the assessments do not decouple it from firewood. Policy decisions based on these factors should therefore be pursued with caution. Urgent research is needed to settle the debate, particularly on the health impacts of charcoal use.

[1] *An approach that prioritises product quality, features and innovation over other factors.*

INTRODUCTION

Charcoal is a primary fuel source for the majority of urban households in Sub-Saharan Africa (SSA), with 30% of the population in this region relying on it (and an equivalent share relying on gaseous fuels) (IEA *et al.*, 2025). Nearly all projections (*e.g.* IEA, 2023) show continued use of charcoal to 2050 and beyond, with its use growing in urban SSA (IEA *et al.*, 2025). Even when households transition to clean cooking fuels, charcoal and other biomass are expected to continue to be in the fuel mix as stacking options.[2] Although the use of unprocessed biomass globally is falling in both urban and rural areas, reliance on charcoal is increasing, especially in urban parts of SSA. In 2023, nearly 157 million people in SSA depended on charcoal for their household energy needs (IEA *et al.*, 2025).

Along with fuelwood, dung and crop residues, charcoal is viewed as a traditional fuel that is harmful to health, the environment and climate. Research into and interventions around charcoal have therefore focused on the elimination of its use. Despite many attempts to improve the efficiency of charcoal end use through fuel-efficient stoves, there is an ongoing shift away from such efforts. For instance, many development funders either implicitly or explicitly decline to support clean cooking solutions that entail the continued use of traditional biomass.[3] Recent research (Gill-Wiehl *et al.*, 2024) shows overclaiming of carbon credits was much greater for biomass-based solutions, which has been used to further strengthen the argument for shifting support away from them. There have been limited large-scale interventions on the supply side of charcoal since the 1990s.

Consistent evidence shows that the clean cooking sector cannot develop without investment in the research and development of technology and fuels, the generation of data for informed decision making, the development of supply chains, and the tackling of the problem of end-user affordability, among other issues. This means that the policy positions taken on certain fuels and technologies have significant consequences for their future development. Such positions should therefore be based on strong evidence. This calls for a detailed analysis of charcoal and the conflicting views regarding its impacts.

This report forms part of the International Renewable Energy Agency's Knowledge Series on renewables-based clean cooking solutions. The series aims to elevate the policy and investment discourse on renewable forms of cooking energy that continue to receive less support relative to their fossil-based counterparts. The series has so far included webinars, whose recordings are available here. The key messages arising from the webinar series were subsequently summarised in a brief titled *Advancing renewables-based clean cooking solutions*, published in March 2024 (IRENA, 2024).

As a continuation of this series, and to improve understanding about renewable sources of cooking energy, this report takes a deeper look at charcoal and assesses whether it can play any role in a modern cooking transition. Achieving this requires first tackling some common controversies that have led to charcoal's negative image. These include conflicting viewpoints about its negative impacts with regard to deforestation, forest degradation, climate change and health. The report is informed by literature review and a field study in Kenya. The main findings of the report were presented for validation by policymakers from six countries, as well as researchers, practitioners, financiers and civil-society actors.

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2 *"Fuel stacking" is the use of additional fuel(s) in combination with charcoal by those who have access to clean cooking fuels.*

3 *Examples include Modern Cooking Facility for Africa and Modern Energy Cooking Services (MECS), which are explicit about not financing charcoal.*

The main issues addressed in the report include the following:

a. **The controversy around charcoal's impacts**
Several controversies surround charcoal's impacts, a situation that creates a challenge for decision making. The study aimed to examine existing evidence and use it to substantiate or question the areas of controversy about charcoal's impacts. A key starting point was to clearly differentiate charcoal from other wood-based fuels, recognising that many misunderstandings stem from conflating the effects of the two fuels.

b. **The feasibility of a transition away from charcoal**
The current policy measures on charcoal across SSA are guided by its perception as a transition fuel, a perception that informs two main policy approaches in charcoal management. The first approach is to take no action on charcoal (as is the case with firewood), instead focusing efforts on making alternative cooking solutions available and affordable, with the expectation that populations relying on charcoal will transition to those solutions. The second approach involves implementing restrictive policies on charcoal, ranging from extremely severe measures (*e.g.* total bans) to restrictions on some parts of the value chain, such as production or transportation. Neither policy approach has been effective, as has been well documented (Ndegwa *et al.*, 2020) and subsequently confirmed in the consultation with policy makers. Setting aside the perception of charcoal as fuel that households in SSA will fully transition away from, this report explores an alternative policy pathway that allows charcoal to continue to meet cooking energy demand but with fewer negative impacts.

Organisation of the report

This report is organised into five chapters. The introduction presents the background and motivation of the study and its approach. Chapter 1 focuses on the role of charcoal as a cooking energy and the concerns surrounding its use. This chapter is presented as a historical evolution to capture important events and timelines that have informed the perceptions about charcoal and the measures taken in response to it. Chapter 2 discusses the key misconceptions around charcoal that the study set out to tackle and offers a new perspective on charcoal by addressing each one of those controversies. Chapter 3 summarises the case study in Kenya and outlines areas where the field study findings support or contradict the literature review findings reported in previous chapters. The last chapters (4 and 5) present a way forward for the sector by proposing a new form of cooking energy – "modern charcoal" – that is distinct from traditional charcoal, using sustainability indicators to support the arguments. Chapter 5 also discusses the potential transition to this modern fuel, with inputs drawn from a validation workshop held with policymakers and other stakeholders.

1. HISTORICAL EVOLUTION OF CHARCOAL CONCERNS

Charcoal is an important energy source. Estimates show that close to a third of the world's rural and urban population relies on this fuel for meeting its cooking energy needs (Sedano *et al.*, 2016). As a cooking fuel, charcoal is considered to be superior to fuelwood because of its higher energy density, lesser bulk and lower emissions at the point of use (Nyarko *et al.*, 2021).

Most charcoal use occurs in SSA. According to the Food and Agriculture Organization (FAO), Africa accounts for 90% of the share of energy use from harvested wood (Dam, 2017). Of the 53 million tonnes (Mt) of charcoal produced worldwide in 2020, approximately 33.9 Mt – representing nearly 64% – was generated and consumed within SSA (FAOSTAT, n.d.). Presently, Africa accounts for up to 65% of global charcoal production, largely driven by the demand for cooking fuel among urban households (Nyarko *et al.*, 2021).

Charcoal use is, however, not restricted to Africa; a proportion of charcoal produced in Africa (21%) is exported to European countries, where it meets 40% of Europe's charcoal demand (Nyarko *et al.*, 2021). Global charcoal imports and exports have been estimated at USD 1.2 billion (Nyarko *et al.*, 2021).

Given the scale of demand for charcoal, the preference for it over other biomass fuels, and the presence of major barriers to switching to alternative cooking fuels (*e.g.* high costs and unreliability of supply), a transition away from charcoal is seen by some as unlikely in the medium and even the long term (Branch *et al.*, 2022; Dam, 2017; Mwampamba *et al.*, 2013). Some researchers argue that cultural preferences, socio-economic dynamics and inherent limitations within the energy ladder framework are likely to sustain the prominence of charcoal within the cooking energy mix across SSA (Alfaro and Jones, 2018).

The rapid population growth and urbanisation trends in SSA also suggest that the region may experience an increase in charcoal demand. This potential increase is supported by an analysis of past trends. A trends analysis spanning three decades found that the average annual production of charcoal in Africa has drastically increased since the 1970s. Starting from a relatively low value of 600 000 tonnes (t) in 1970, it rose to close to 3 Mt in 2017, where it remained until 2019 (FAOSTAT, n.d.). As an example, in Kenya the demand for charcoal increased by 82% between 2001 and 2021 (Kirimi *et al.*, 2023). These demand trends are projected to continue (Ndegwa *et al.*, 2021). Charcoal production worldwide trebled within a 50-year timeframe, from 17.3 Mt in 1964 to volumes of up to 53 Mt between 2014 and 2018 (FAOSTAT, n.d.; Nyarko *et al.*, 2021), with over half the production (64%) occurring in Africa (FAO, 2020).

Increased charcoal production and consumption trends have been attributed to population growth. With Africa's population projected to triple or quadruple by the end of this century (Kazeem, 2020), it is difficult to foresee a scenario in which charcoal plays a reduced role in household energy consumption.

Other factors likely to drive charcoal demand include increasing economic hardship in rural and urban areas and the depletion of firewood resources in rural areas. The United Nations (UN) projects that 3 billion people are expected to live in slums in Africa and Asia by 2050 (United Nations, n.d.). Poor people will not be able to afford to transition to alternative cooking fuels even if they become available. Past trends show that where some share of a population has been able to afford to transition to clean fuels, charcoal has remained in use as a secondary fuel. Of equal concern is the fact that rural users are subsidising and bearing the brunt of urban charcoal consumption. They cannot afford to cook with charcoal even though they produce it, and their access to fuelwood is impacted by the unsustainable extraction of wood for charcoal that targets urban markets (Ezzati and Kammen, 2002).

Despite its important role as a cooking energy source, there have been minimal technological advances in the charcoal sector, which still bears characteristics similar to those of half a century ago. The sector is still largely informal and not captured in national planning; uses rudimentary and extremely wasteful technology for production; lacks the most basic data, such as production and consumption volumes; and is still seen as a problem rather than as a solution to the energy access challenges being faced today.

The following section provides an overview of the history of the woodfuel[4] sector's development and policy concerns that have arisen at various times during its evolution.

The woodfuel crisis
(mid-1970s to 1980s)

Concerns regarding the availability of fuelwood emerged in the mid-1970s, driven by the realisation that vast and expanding populations in developing nations relied heavily on fuelwood as their primary source of domestic energy (Arnold and Persson, 2003). Rising population levels were projected to lead to a depletion of fuelwood resources, culminating in a severe shortage. In response, increasingly desperate communities were expected to encroach on previously undisturbed forested areas, thereby accelerating large-scale deforestation. Also referred to as "the other energy crisis", it was predicted that this would be worse than the energy crisis associated with the rise in petroleum costs. Questions were being raised about what would happen if wood were to run out. The policy response was to make massive investments in forest programmes to secure wood-based energy (Dewees, 1989).

Debunking the woodfuel crisis
(late 1980s to 1990s)

The woodfuel crisis of the 1970s was followed by reassessments of the wood energy landscape. The results indicated that in most regions (examined through localised studies), there was neither a clear nor an imminent deficit in wood energy supply. The majority of deforestation during that period was primarily attributed to agricultural expansion. The presence of firewood collection on cleared land did not necessarily imply causation; rather, it was the clearing of forested areas that made firewood available. Moreover, various studies conducted at the time (*e.g.* Dewees, 1989) found that: i) most firewood was not sourced from forests, but from trees located in agricultural land and peripheral woodlands; and ii) the firewood predominantly consisted of dead branches and shrubs, rather than live, mature forest trees. The policy response, according to Arnold and Persson, was to hugely scale back on programmes that had been designed to tackle the crisis, for example, afforestation programmes (Arnold *et al.*, 2003).

Persistence in associating charcoal with deforestation
(1990s)

Despite the results of the new assessments, associating deforestation with woodfuel demand persisted even as forestry programmes were being scaled back. A United Nations Development Programme/World Bank study (UNDP and World Bank, 1987), for instance, confirmed that there was no woodfuel availability crisis in the 1980s but predicted that one would occur in the mid-1990s because there would be scarce agricultural

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[4] *Since no clear distinction was made between charcoal and firewood until recently (post 2000), the arguments presented can be applied to both fuel types.*

land for sourcing charcoal feedstock. Charcoal producers would therefore turn to large-scale clearing of land for charcoal as the primary produce.

Studies from the 1990s, however, found no such evidence. In Zambia, charcoal was associated with land clearing (up to 50% of the total woody biomass removal in certain locations), but this clearing was not expected to lead to deforestation because the woodland had high regeneration potential. The CHAPOSA study by Stockholm Environmental Institute (Ellegård *et al.*, 2002) found that charcoal production in both the United Republic of Tanzania and Zambia in the 1980s and 1990s was not responsible for permanent environmental damage. This is consistent with previous studies (Hosier and Dowd, 1987) that reported high potential for regeneration of vegetation removed during charcoal production. Post-harvest management techniques such as coppice management, sprout protection and fertilisation were able to improve the landscape, except in situations where there were several waves of tree harvesting and heavy grazing pressure. It is the latter pressures – if prolonged in a land with low productivity, as opposed to harvesting of woodlands for fuels – that would lead to environmental degradation. Despite this evidence, policy responses were still informed by concerns of deforestation linkages and included country-level bans on the production and trade of charcoal (Ribot, 1993). On the other hand, donor-funded afforestation programmes continued to be scaled back.

"Woodfuels", "fuelwoods", "biomass" and localised impacts (2000-2010)

Part of the confusion was in the definitions, leading to a mix-up of the impacts of firewood and charcoal. In the 1970s, FAO and World Bank reports grouped all wood-derived fuels under broad labels such as "fuelwoods" and "woodfuels". Neutral environmental impacts of fuelwood, *e.g.* its collection from dead material, had thus been misattributed to charcoal, too. Research in the late 1990s-2000 period made clear distinctions between the two fuels, noting that charcoal, unlike firewood, usually comes from trunks or large limbs and requires cutting trees (Girard, 2002). Multiple studies have shown that although charcoal is not always the main driver of deforestation, it can substantially contribute to the degradation and loss of forests that are already disturbed (Hofstad *et al.*, 2009). Evidence that hardwood was being consumed faster than it could regenerate amplified these concerns. While sustainable forestry practices could, in principle, maintain these stocks, such practices were often absent due to cost and other constraints (Naughton-Treves *et al.*, 2007). As a result, it became increasingly recognised that although woodfuel is not a major driver of deforestation globally, its impacts can be considerable at the local level.

While the late 1990s had seen some studies suggesting the negative impacts of charcoal (Brouwer and Magane, 1999), later work highlighted the socio-economic benefits of charcoal. Studies in southern Mozambique found that charcoal formed 60% of the annual income of producers (Herd, 2007). In the United Republic of Tanzania, charcoal was an important source of income for 75% of the farmers in investigated areas (Ellegård *et al.*, 2002; Monela *et al.*, 2007; Seidel, 2008). In Zambia, with the collapse of the agricultural market, charcoal was found to be the only income source in rural areas (Falcão, 2008). Informed by several studies in southern Africa, the Stockholm Environmental Institute (Kalumiana, 2000) observed that charcoal was a major forest produce, and at times the only produce, thus emphasising its importance.

Few interventions occurred during this period. In 2006, only two African countries (Kenya and Sudan) had charcoal-related policies (Mugo and Ong, 2006). Zulu (Zulu, 2010) reports on a conference of ministers in South Africa that discussed common approaches to energy access and low-carbon economic growth and failed to even mention charcoal.

Large-scale introduction of improved cookstoves
(early to late 2000s)

The 2000s saw the formation of the Global Alliance for Clean Cookstoves (GACC, now the Clean Cooking Alliance). Many cookstove efforts by nongovernmental organisations (NGOs) and other donors coalesced around GACC because it was meant to co-ordinate the efforts of the entire cooking sector. With its clear mandate, targets, political goodwill and financing, the GACC's efforts led to the large-scale introduction of improved cookstoves, including those supported by the private sector.

However, there were two major concerns about the approach. First, a heavy focus was initially placed on rural areas, concurrent with the general focus area of development programmes. Most of the solutions introduced were therefore targeted at rural fuelwood users. While charcoal is produced in rural areas, the target consumers are urban. Secondly, GACC, per its name, focused on the utilisation rather than fuel supply side, which means the production side of charcoal was not its focus. The fact that other organisations were following GACC's strategy and using its indicators to assess their own progress (and to report to GACC) meant that the charcoal supply side was ignored not just by GACC itself, but also by other organisations that became part of the umbrella body.

Evidence of climate and health impacts
(early to late 2000s)

The health and climate impacts of traditional cooking fuels became a prominent subject during this period, with evidence showing the significant impact of indoor air pollution from fuelwood on health (WHO, 2007). At the same time, life-cycle assessments of charcoal showed significant climate impacts from production to transportation and through to its use. On the production side, emissions from charcoal were linked to deforestation, despite the evidence to the contrary. The policy response at the time was to pursue win-win-win solutions. The cooking solutions that warranted support had to address concerns about energy, health and the climate. Efforts became increasingly focused on "truly clean" cooking solutions that could realise all three benefits.

Evidence of the health benefits of cookstove interventions (predominantly the improved biomass stoves, which were promoted at the time) became established through rigorous studies such as a randomised cookstove intervention trial in Guatemala (Smith-Sivertsen *et al.*, 2009). The results showed limited health benefits associated with switching from traditional to improved biomass stoves. Charcoal was lumped together with firewood into "traditional" and "polluting" fuels that households needed to transition away from.

The policy response was a scale-back of international development funding for biomass cookstoves. Key organisations such as GIZ and EnDev that had been supporting improvements in biomass cooking technologies and fuels started shifting away from them.

From improved cookstoves to clean cooking
(2010-2020)

Through the support of the World Health Organization (WHO) and GACC, the International Organization for Standardization (ISO) standards for clean cookstoves and fuels were developed and became widely adopted in this period. The standards established criteria for defining what constitutes a "clean" cookstove, distinguishing it from traditional and "improved" cooking technologies. These criteria were used as a benchmark for cooking energy promotion efforts. Very few charcoal stoves fell into the clean category. While firewood stoves also failed to meet the clean criteria, some still received support (*e.g.* Envirofit stoves) due to the rural target population and prior efforts by GACC.

In 2015 the Sustainable Development Goals (SDGs) were globally agreed upon, followed closely by the Paris Agreement on Climate Change. SDG7 targets universal access to modern cooking energy for all by 2030. With WHO as the custodian agency for SDG7's clean cooking indicator, the definition of modern cooking energy leans towards solutions that meet health standards.

This period also saw significant private sector investments in liquefied petroleum gas (LPG), electricity, ethanol and biogas-based cooking solutions using innovative business models that enabled these cooking options to be purchased in small units like charcoal. Importantly, they focused attention on urban markets that had been ignored by past development efforts. Innovative financing, like carbon finance and results-based finance (RBF), enabled them to rapidly expand minor and reach a relatively good share of markets in countries like Kenya and Rwanda. Charcoal prices continued to rise over this period, often as a result of charcoal bans, with prices reaching levels comparable to alternative fuels. However, contrary to the energy ladder hypothesis, charcoal continued to remain in wide use.

Policy paralysis?

(2020 to date)

With just five years left to the expiry of the SDGs, charcoal remains the predominant cooking fuel for urban households in major urban centres of Africa. The period 2010-2020 saw a peak in clean cooking interventions, yet they have made a very small dent in charcoal use. The current trends point toward continued use of charcoal in the future. At the same time, concerns are rising about charcoal's negative environmental impacts due to the growing demand from population growth, urbanisation and decline in biomass stocks caused by deforestation (Doggart *et al.*, 2020). Urgent interventions are therefore required.

Currently there are no large-scale, evidence-informed, sustained interventions on charcoal beyond the two policy approaches outlined earlier that have demonstrated ineffectiveness. Fifty years of neglect of the sector have transformed it from a neutral-to-low environmental impact sector into an energy and environmental crisis that was alarmingly but mistakenly posited as woodfuel crisis in the 1970s.

Tackling the controversies surrounding charcoal could break the policy impasse and lead to the pursuit of realistic options for the modernisation of cooking technologies and fuels in Africa while guaranteeing long-term energy security.

2. RE-EVALUATION OF MAIN CHARCOAL CONTROVERSIES

Most adverse positions on charcoal have been related to its impacts. These have in turn influenced perceptions on cooking energy transitions, as well as policy direction. This section reviews the main charcoal controversies.

FOREST DEGRADATION AND DEFORESTATION

The relationship among charcoal production, forest degradation and deforestation is complex and widely debated. Some studies report a relatively small contribution from charcoal – for example, less than 7% in one site-specific assessment (Chidumayo, 2019) – while others identify it as a major driver of forest degradation, arguing that charcoal demand increases logging and directly reduces forest cover (Sedano *et al.*, 2016; Van der Plas, 1995).

Historically, viewpoints have swung from viewing charcoal as a cause of widespread deforestation, to claiming it has little impact, and finally to recognising its role in localised forest loss. Minten *et al.* (2013), for instance, found that combined charcoal and firewood use accounted for more than 70% of forest loss, with charcoal alone responsible for over 40% of that loss. Similarly, Minten *et al.* (2013) observed that charcoal production had become a major driver of deforestation in much of Madagascar's coastal region, contributing up to 75% of forest loss. Sedano *et al.* (2022) argue that charcoal-driven forest degradation is largely separate from agriculture-driven deforestation (*i.e.* not all charcoal is derived from land cleared for agriculture) and that the degrading impact of charcoal production can be as severe as deforestation.

Tree cutting for charcoal production occurs along a spectrum – from selective harvesting to clear-cutting – making it difficult to distinguish its effects on deforestation from those on forest degradation (Van der Plas, 1995). For many years, the central debate focused on whether charcoal production directly drives forest clearing or whether it is largely a by-product of land being converted to other uses, particularly agriculture. Evidence supports both perspectives, depending on local practices and context. In central Zambia, for example, nearly 70% of forest cleared for charcoal production was later converted to farmland and settlements (Chidumayo, 2002). Arnold and Persson (2003), drawing on multiple studies, noted that charcoal is often produced from forests already being cleared for agriculture, reinforcing the view that charcoal production is rarely the primary cause of large-scale forest loss. Similarly, Chidumayo and Gumbo (2013) reported that charcoal production accounted for less than 7% of total deforestation in most tropical countries. Deforce *et al.* (2013) found that earth kilns in Zambia occupied only about 5% of the total harvested area – representing the portion permanently deforested due to charcoal production. Much of the remaining area used for charcoal was degraded rather than fully cleared, with strong potential for recovery if well managed and not converted to other land uses (Deforce *et al.*, 2013).

While some of the arguments presented above appear to diminish concerns about charcoal's environmental impact (*i.e.* as causing forest degradation as opposed to deforestation), their relevance may be outdated, since the current period is characterised by an unprecedented demand for charcoal. Oduori *et al.* (2011) reported that severe wood resource depletion led to stumps from previous charcoal harvesting, which are usually left to regenerate, being dug up and converted into charcoal, leading to permanent deforestation even without a change in land use. Whereas, Sedano *et al.* (2016) contend that the level of forest degradation caused by charcoal production can be comparable in magnitude to outright deforestation.

The entire debate on deforestation versus forest degradation from charcoal production loses further significance in decision making as demand continues to grow to unprecedented levels. The scale of destruction is so vast that the line between degradation and deforestation has become thin. It could reasonably be argued that the distinction between deforestation and forest degradation is of lesser importance and more focus should be on the implications of extensive tree harvesting for charcoal. For instance, selective cutting for charcoal production can cause the depletion of preferred species (Arnold *et al.*, 2003). If this leads to adverse effects on the composition and productivity of forests, the consequences of charcoal production would equate to those of full clearing of forests. Indeed, Chidumayo *et al.* (2013) observe that while deforestation caused by charcoal is small at a broader scale (national and regional), it has serious consequences on a local scale. Such localised impacts have been a major concern for governments, leading to sweeping decisions such as charcoal bans. In Kenya, for instance, where the national government lifted charcoal bans, several regional governments continued to institute the bans to avert localised deforestation. The presence of charcoal makers in forests, harvested tree stumps, and highways lined with charcoal bags for sale have been enough to influence such decisions.

There is no universally accepted definition for forest degradation (Aryal *et al.*, 2021), and each country decides what a "degraded forest" means within its own landscapes. The maxim "forest quality matters as much as quantity" supports the argument for shifting focus away from definitions to visible impacts. The Rainforest Alliance, for instance, views the result of severe and sustained degradation as deforestation (Rainforest Alliance, 2024). Questions about whether degraded forests will regenerate in the long term and what land use changes will occur following the depletion of the forest cover can only be answered retrospectively. The answer to the question of what constitutes a degraded forest is also highly variable and context-specific; it depends on, among other issues, the scale of charcoal production, the type of forests in which the production occurs and the socio-economic conditions of the region (van Uhm *et al.*, 2022).

The important services that are lost over the period when the forest is degraded should be the main concern. The serious consequences of forest degradation are generally underappreciated, and their importance could

be undermined when so much focus is placed on answering the deforestation-versus-forest degradation question. In Nigeria, Amankwah (2019) reported that little attention was paid to vegetation loss within certain zones because it was not formally categorised as deforestation, and the role of charcoal that was contributing to the vegetation loss was missing in the energy transition discussions. Some observers contend that the Reducing Emissions from Deforestation and Forest Degradation (REDD+) policy instrument focused overwhelmingly on deforestation and paid scant attention to forest degradation, leading to a missed opportunity to tackle its important drivers – like charcoal production (Ahrends *et al.*, 2010).

When the distinction between the two issues is set aside and the focus is placed on the impacts, the behavioural and technological factors that drive the processes gain more prominence. The technical characteristics of the kiln and how it is operated, for instance, play a significant role in determining its efficiency and subsequent impact on forest degradation. About half of the energy in fuelwood is typically lost during the conversion of wood to charcoal when using traditional kilns (Kammen and Lew, 2005). Charcoal producers' indiscriminate tree-clearing practices, which include felling all mature trees, is also an important impact factor (Schure *et al.*, 2019). With proper regulations, these factors can be controlled.

Summary

The evidence associating charcoal production with forest degradation is extensive and does not give rise to major controversies. What remains debatable is whether charcoal production contributes to deforestation. Several authors argue that on a large scale, it does not (Ahrends *et al.*, 2010; Arnold *et al.*, 2003; Boucher *et al.*, 2011; Chidumayo, 2002; Ellegård *et al.*, 2002; Khalifa and Aworry, 1982; Ribot, 1993), while others argue it might lead to deforestation in specific settings (Arnold *et al.*, 2003; van Uhm *et al.*, 2022).

With increasing population and high cost of living driving the dependence on charcoal across SSA and the projections of this trend continuing, a mere association between charcoal production and forest impacts should be enough to motivate action. The more relevant question is, therefore, what can be done to curb charcoal production's widely reported negative impacts.

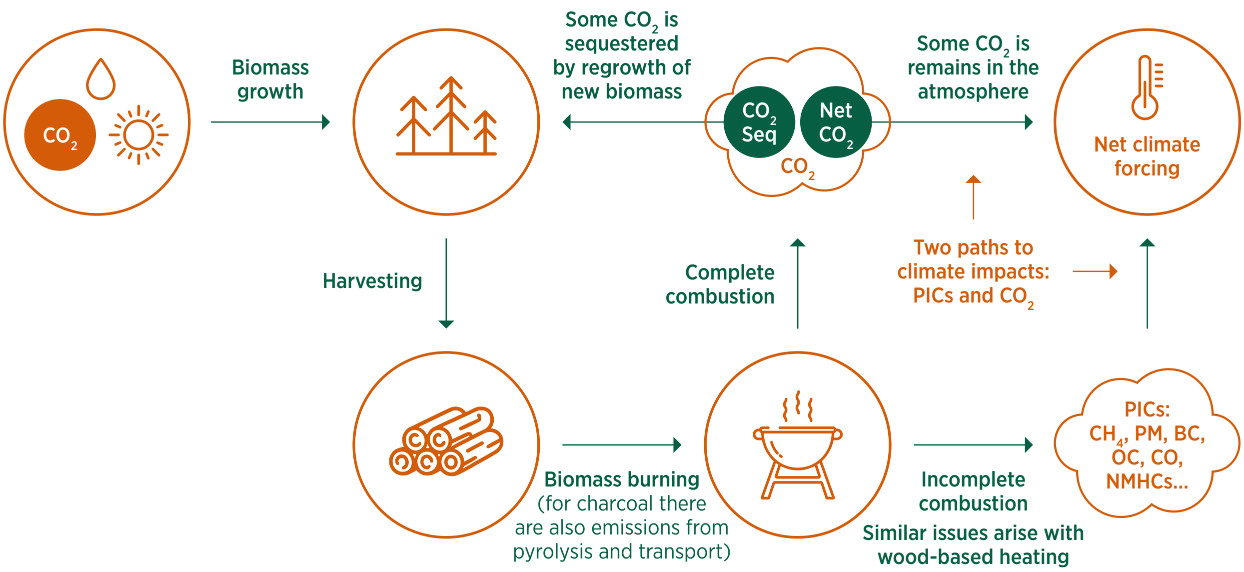
CLIMATE IMPACTS

Unlike firewood, charcoal is associated with substantial upstream emissions generated during extraction, production and distribution. One major pathway is deforestation, as forests function as carbon sinks. Emissions linked to forest degradation, however, remain poorly quantified, and relatively few studies explicitly incorporate them into carbon accounting. Yevich and Logan (2003) and Chidumayo *et al.* (2013), using survey data and national statistics, produced early estimates of carbon emissions from charcoal in Africa. Yet a significant share of charcoal production goes unrecorded in national statistics, limiting the accuracy of such assessments (Mwampamba *et al.*, 2013).

At the extraction stage, harvesting wood faster than it regenerates results in net positive greenhouse gas (GHG) emissions. This concern is validated by the fact that much of the wood used for charcoal is not sourced from plantations, and harvesting rates in many regions already exceed natural regrowth. For example, Campbell (1996) estimated annual woodfuel yields of about 2-3 tonnes/hectare (t/ha) in African miombo woodlands, while Hofstad *et al.* (2009) estimated yields of 2-4 t/ha per year in Ugandan *Combretum* woodlands. Charcoal producers, however, often harvest at significantly higher rates. In Uganda, large areas of woodland were found to lose an average of 3 t/ha of air-dry biomass annually due to harvesting pressures (Hofstad *et al.*, 2009).

Beyond deforestation-related emissions are those arising directly from carbonisation and use. Charcoal is produced by pyrolysing wood and venting the resulting gases to the atmosphere. This controlled, oxygen-limited process leads to incomplete combustion: it generates charcoal while emitting GHGs – including methane (CH_4) – associated with incomplete combustion (Figure 1). Thus, charcoal production contributes to climate change through emissions of both carbon dioxide (CO_2) and CH_4. Ajibola *et al.* (2020) estimate that 2 billion t of charcoal are burned annually, releasing about 7 billion tonnes of CO_2 equivalent (tCO_2) as it oxidises. Bailis *et al.* (2004) found that cooking a single meal with charcoal generates a global warming impact two to ten times higher than cooking with firewood, and five to sixteen times higher than using kerosene or LPG, depending on which gases are included in the life-cycle assessment and the degree of forest regrowth permitted. This helps explain why countries that are heavily reliant on woodfuels tend to have a large share of emissions originating from their household sector.

Figure 1 How woodfuels impact health and climate



Source: Courtesy of: R. Bailis, Stockholm Environment Institute.

Based on observations from 11 kilns across multiple studies, emission factors for charcoal production were estimated at 1788 grammes (g) CO_2/kilogramme (kg) of charcoal and 32 g CH_4/kg of charcoal. In tropical ecosystems in 2009, charcoal production was estimated to emit 71.2 million tCO_2 and 1.3 million tonnes of methane (tCH_4) (Isese, 2019). According to Bailis *et al.* (2004), total emissions from charcoal production and use in Kenya – one of the largest charcoal consumers in SSA – were equivalent to emissions from the country's transport and industrial sectors, even assuming full regrowth of harvested wood (Bailis *et al.*, 2004).

Charcoal contributes less to climate change at the point of consumption than during production. Kammen and Lew showed that emissions from production have a far greater warming effect than emissions from charcoal combustion (Kammen *et al.*, 2005). Others (Norconsult Tanzania Limited, 2002) similarly found that fuelwood and charcoal burning contribute notably to emissions of CH_4 (46%), carbon monoxide (CO) (42%) and non-methane hydrocarbons (NMHCs) (44%), but less so to CO_2 (32%). Even so, end-use emissions remain modest relative to those from production.

Summary

It is well established that the carbonisation of charcoal creates emissions. In addition to CO_2, the pyrolysis of biomass also produces incomplete combustibles such as CH_4. Climate-related emissions at end use are fewer but not negligible (Bailis *et al.*, 2004). Surprisingly, most interventions (cookstove interventions) focus on the level of use, where both health and climate impacts are fewer, rather than the production level, where there are significant environmental impacts. Although efficient stoves significantly reduce the amount of charcoal consumed and could therefore impact overall demand and production quantities, a major opportunity is lost by not intervening at the production level.

HEALTH IMPACTS

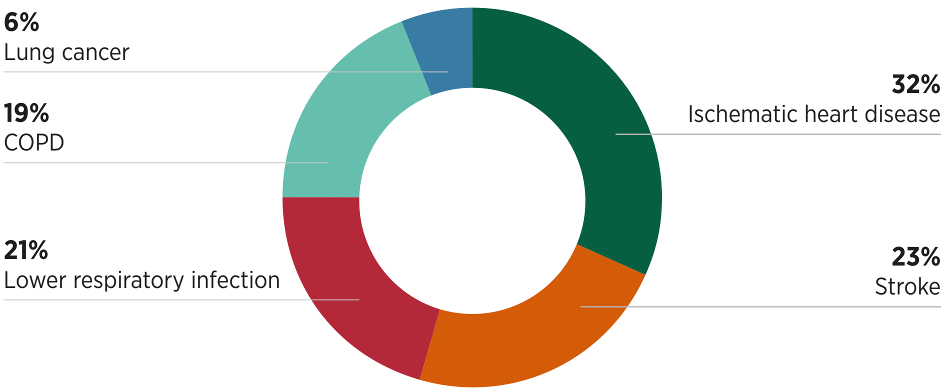
The literature contains two opposing accounts of the relationship between charcoal use and its health impacts. To settle the debate, it is important to explore whether the use of fuelwood, crop residues and dung result in more negative health impacts compared to charcoal or, conversely, whether a switch away from any of these fuels to charcoal improves health. Answering these questions also requires appraising the general evidence linking cooking smoke exposure and health.

One point of view tends to lump charcoal with firewood into a biomass category and attributes some negative health impacts of firewood to charcoal. Examples of health impacts that have possibly been misattributed to charcoal include acute respiratory infections (ARIs), chronic obstructive pulmonary disease, hypertension, stroke, heart attack and lung cancer.

According to the WHO, 3.2 million annual deaths are attributable to cooking with polluting fuels, a collective term that includes both firewood and charcoal.

The majority of deaths per year that are caused by cooking-related household air pollution (HAP) exposure are from ischaemic heart disease and stroke (Figure 2). In epidemiological studies, cardiovascular disease outcomes , due to their chronic nature, are usually measured using blood pressure as a proxy (Clark *et al.*, 2013; Gabdrashova *et al.*, 2021; Giorgini *et al.*, 2016; Kumar *et al.*, 2021; McCracken *et al.*, 2007; Onakomaiya *et al.*, 2019). Several of these studies, which include systematic reviews, have looked at the evidence linking cooking smoke and cardiovascular disease-related health effects and have confirmed an association. However, most of these studies have not distinguished charcoal from fuelwood. Because charcoal is a pre-processed fuel, it has lower emissions of pollutants associated with cardiovascular disease (*e.g.* particulate matter of less than 2.5 microns [$PM_{2.5}$]) at end use than firewood (Bailis *et al.*, 2004).

Figure 2 Causes of 3.2 million deaths from the use of polluting cooking fuels



Source: (WHO, 2024).

With limited intervention studies offering a "gold standard" in the attribution of health impacts to various cooking technologies, observational studies that entail HAP measurements in kitchens or at personal levels have been generally applied in health impact assessments. This information is usually combined with published data on exposure-response relationships between air pollution exposure and various health outcomes. This research approach raises a concern because it makes it impossible to rule out the effect of confounding factors, such as poverty and ambient air pollution.

Studies with health outcome measurements

Lower respiratory infections, specifically acute lower respiratory infections in children under five years, are among the most extensively studied primary health outcomes linked to biomass fuel use (Figure 2). A number of studies have investigated the association between respiratory infections and charcoal use, some of which are discussed below.

In 2016, Woolley *et al.* (2020) observed increased shortness of breath, cough and ARI among children living in households that cook with firewood compared to households that cook with charcoal. All the associations were statistically significant, leading the authors to conclude that replacing wood with charcoal cooking fuel may lead to health improvements in the study area (urban Uganda).

In 2017, Sana *et al.* (2019) showed that women living within an urban area in Burkina Faso using wood for cooking had an increased risk of cough compared to those using charcoal for cooking. The cases of ARI in charcoal users was half the number of cases in fuelwood users.

In Sierra Leone, ARI prevalence was observed to be higher for children in households using firewood compared to those using charcoal stoves (Taylor and Nakai, 2012). Similarly, in Malawi, Fullerton *et al.* (2009) found that users of wood as a primary cooking fuel had significantly worse lung function than users of charcoal.

Using two years of health data collected from Kenyan families using wood and charcoal, Bailis *et al.* (2004) found that children and men in households using charcoal had 44% fewer cases of acute lower respiratory infections compared to wood users; women had 65% fewer cases. The authors suggested promoting charcoal as a near-term alternative to unprocessed fuelwood (Bailis *et al.*, 2004).

A 1993 report from Zambia (Ellegård and Egnéus, 1993) found no difference in health outcomes between charcoal and modern fuels, but significantly worse health outcomes in firewood users compared to users of other fuels, including charcoal. Similarly, in Mozambique (Ellegård, 1996), no difference in health outcomes (cough) was observed between users of charcoal and users of modern fuels.

Conversely, in Uganda, North *et al.* (2017) found that people living in homes where charcoal was used for cooking were more likely to have respiratory symptoms than those cooking with firewood. This contradicts the findings of other studies that have found respiratory symptoms to be worse in wood than charcoal users.

Very few studies have investigated non-respiratory infections. A recent systematic review (Idowu *et al.*, 2023) summarises the findings from those studies. One study associated charcoal use with reduced overall weight and body mass index, one with reduced birth weight of children, and one with sick house syndrome. There are however various quality concerns with the studies, including the small samples investigated and a lack of clarity about the health outcome of concern that prompted the study (*e.g.* lower or higher weight).

Health impacts relating to charcoal production have also been reported. They include production accidents, poison from the tree species harvested, sickness from smoke and dust, and charcoal burns (Kamwilu *et al.*, 2021). Idowu *et al.* (2023) found that charcoal production workers were exposed to occupational health hazards such as physical injuries from handling the feed stock and final product, and exposure to chemicals emitted during the charring process. According to a 2010 report from Zulu, restrictions on charcoal production and trade through legal measures exposed small-scale producers to mistreatment and physical violence (Zulu, 2010).

Studies with exposure measurements

When linking cooking smoke exposure to wide-scale health impacts, $PM_{2.5}$ is the main pollutant of public health concern, as covered in the global burden of disease of HAP (WHO, 2007).

Few studies have assessed the exposure to pollutants from charcoal separately from fuelwood. In the *Global household air pollution database,* for instance (Shupler *et al.*, 2018), just 6 of the 187 compiled studies evaluate charcoal as the main or distinct fuel.

In Kenya, households using charcoal had 88% lower $PM_{2.5}$ levels (500 microgrammes [µg]/cubic metre [m^3]) compared to households using wood in an open fire (concentrations of over 3 000 µg/m^3) (Bailis *et al.*, 2004). In Sierra Leone, there were significantly higher concentrations of suspended particulate matter in the kitchens of households using firewood stoves relative to those using charcoal stoves (Taylor *et al.*, 2012). In Zambia, wood users had the highest levels of particulate exposure (890 µg/m^3) and charcoal users had intermediate levels (380 µg/m^3), while electricity and LPG users had the lowest exposure (240 µg/m^3) (Ellegård *et al.*, 1993).

In Accra, Ghana, wood users had the highest $PM_{2.5}$ levels, followed by charcoal users; kerosene, LPG and electricity users (combined) had the least (McGranahan, 1993). While the difference between wood and charcoal users was statistically significant ($p=0.022$), it was marginally significant between charcoal and kerosene, LPG and electricity.

Charcoal combustion also emits other pollutants, of which CO is the most studied. Several studies have found CO concentrations to be higher in households that use charcoal than those using fuelwood and modern fuels (Dionisio *et al.*, 2012; Legonda *et al.*, 2013; Nakora *et al.*, 2020). Other pollutants that have been assessed include endotoxin, which has been found to be higher in wood (40 endotoxin units/m^3) than charcoal burning households (24 endotoxin units/m^3).

Cases of CO poisoning from the use of charcoal in cooking and associated deaths have been variously reported (CLEAN-Air(Africa), 2024). However, no robust evidence of CO poisoning on a massive scale has been linked to the use of charcoal for cooking in SSA.[5,6] Chronic exposure could be a major concern and is included in the WHO indoor air quality guidelines (WHO, 2014). However, the burden of disease estimates that currently influence policy decisions are not based on chronic exposure to CO, but to $PM_{2.5}$.

Risk assessment studies

A recent study (Berkouwer and Dean, 2023) looked at the health impacts of repeated spikes in air pollution ($PM_{2.5}$) that typically characterise traditional cooking practices, focusing on urban settings (where charcoal use tends to be dominant, relative to fuelwood in rural areas). In the study, improved stove ownership reduced air pollution between early morning and late evening hours when cooking occurs, but it had no effect on pollution during the remaining hours of the day. In the same study, pollution levels remained high during non-cooking hours, a finding that was attributed to exposure from traffic-related air pollution while commuting, as opposed to cooking. Because of the high ambient pollution levels, the benefits of an improved stove intervention on overall exposure (and consequently health) was very low (2% reduction). Very similar results were obtained in a study in peri-urban Ghana (Shupler *et al.*, 2024), which found that the mean $PM_{2.5}$ kitchen concentration was only 4 µg/m^3 higher in households cooking with charcoal compared to those cooking with LPG.

Summary

The findings of the studies that have focused on charcoal have some key implications. Collectively, they show that there is no significant difference in $PM_{2.5}$ levels and respiratory health outcomes between charcoal users and modern fuel users, particularly in urban settings where charcoal use is concentrated.

While the findings do not support the argument that cooking with charcoal in place of wood minimises health impacts, as others have posited, they do show that changing the stove or fuel type alone (*e.g.* fuelwood to charcoal, traditional to improved charcoal stove, or even charcoal fuel to LPG) in urban settings where ambient air pollution is high would not confer significant health benefits. This argument is strengthened by an intervention study (Clasen *et al.*, 2024) conducted in a rural community where ambient pollution is low and with a much cleaner fuel (LPG). The switch to LPG did not confer significant health benefits. Based on the current evidence, therefore, the health argument for clean cooking transitions away from charcoal (and the converse – of transitions towards charcoal for health gains) do not appear strong when the pollutants of primary concern are CO and $PM_{2.5}$. This should not be interpreted as ruling out the public health significance of a transition from charcoal, but rather that strong evidence of its benefit is currently lacking, which makes it an important area for further research. Studies that include comparative exposure and health outcome measurements among firewood, charcoal and modern cooking fuels would be particularly useful.

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[5] *Outside SSA, in Asia in particular, charcoal burning is a common suicide method, with up to 18% of suicide deaths attributed to it (Lee et al., 2002).*

[6] *Not explored in this study is fuel safety, which characterises both traditional and alternative fuels like LPG, ethanol and electricity. Explosions linked to LPG, for instance, have been a long-standing concern in some countries.*

SOCIO-ECONOMIC IMPACTS

Charcoal production has been an essential anthropogenic activity since the prehistoric era (Medina-Alcaide *et al.*, 2015). In the present, employment and livelihoods benefits are among the commonly cited advantages of charcoal production (Arko *et al.*, 2024; Dam, 2017; Girard, 2002; Minten *et al.*, 2013; Mugo *et al.*, 2006; Nyarko *et al.*, 2023; Tassie *et al.*, 2021; Zulu and Richardson, 2013). Charcoal and the charcoal value chain provide direct and indirect employment in production, manufacturing (*e.g.* of stoves), transport and trade. Case studies from several SSA countries credit the charcoal value chain with the employment of large numbers of both rural and urban residents who would otherwise be unemployed. FAO, for instance, estimated that the charcoal sector was a source of income for 40 million people in 2017. One study estimated that populations relying on charcoal in both the United Republic of Tanzania and Uganda obtained up to 70% of their annual income from it (Zulu *et al.*, 2013).

Charcoal is therefore a significant contributor to livelihoods, especially in rural areas, where its production takes place. It is estimated that half of all the wood extracted from forests worldwide is used for fuel, and 17% of this is converted to charcoal, generating income for 40 million people (Abbas *et al.*, 2016; Dam, 2017).

Unlike other impact areas, the socio-economic impacts and livelihood benefits of charcoal production have not been the subject of any controversies to date. All the evidence paints an overtly positive picture. It is nonetheless important to challenge the overwhelming consensus on positive socio-economic impacts in key areas such as the distribution of benefits (winners and losers in the industry), generational impacts, and the sustainability of livelihoods built around charcoal in the context of dwindling resource availability. (The fact that charcoal production and use has sustained peoples' livelihoods since the medieval period does not imply that it can continue to do so in the future).

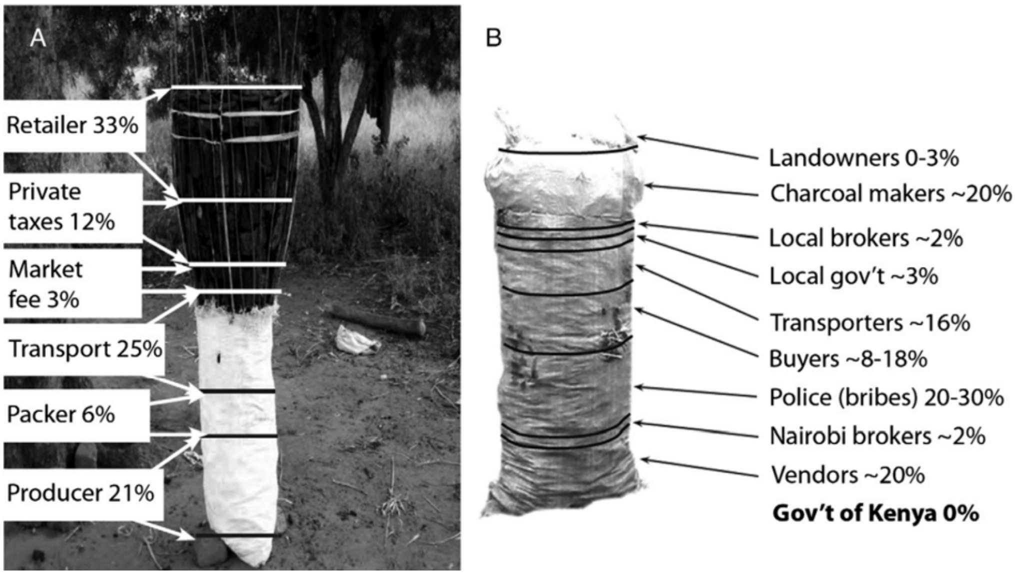
The goal here is not to undermine the benefits of charcoal production. Rather, the issue to consider is: if the sector is so beneficial in its current unregulated form, then either i) a transition away from charcoal would inflict serious harm if not properly planned, which is the case currently; or ii) the benefits could be amplified if the sector were transformed and modernised.

The livelihood benefits in a context of scarcity are an important area of re-evaluation. The societal systems that regulated charcoal production and use in the past no longer exist, and the high demand that drives unsustainable production methods cannot in any way compare to those that applied when the industry was supporting the livelihood of a few producers with access to abundant resources.

One example of this change in conditions is presented in a detailed account of the Sissala community in the Upper West Region of Ghana (Brobbey *et al.*, 2019). The community was traditionally dependent on the charcoal trade, which was fully integrated into its members' livelihoods. Continuing the practice in current times has, however, entailed community members leaving their homes for extensive periods in search of richer vegetation to sustain their charcoal trade. In the process, they have extended the practice to other regions, leading to wide-scale ecological impacts. In one of the regions of their migration (Gonja), the Sissala producers transformed charcoal from a small-scale industry based on wood gathered from land cleared for agriculture into an unsustainable commercial production (Ablo *et al.*, 2022). Furthermore, the traditional systems, such as the issuance of permits by traditional leaders that ensured sustainable production, are no longer adhered to, leading to conflict with host communities (Ablo *et al.*, 2022).

A second important matter to consider is who benefits from the trade. The socio-economic impacts of charcoal vary by the type of producer, which is classified into three categories: occasional, seasonal and full-time (Arko *et al.*, 2024; Girard, 2002). The graduating levels of engagement affect the returns from the activity, the livelihood impacts, and how they would evolve if resources become scarce should the sector be regulated or continue in an unregulated manner. Figure 3A (Malawi) and 3B (Kenya) by Zulu *et al.* (2013) illustrate how charcoal producers who expended significant time and labour in charcoal production received only 20% of the revenue from the charcoal produced and sold. In addition, illegal police bribes accounted for 20-30% of revenue in Kenya and "private taxes" took 12% in Malawi. This is lost revenue that could go towards financing modern cooking transitions, which are severely constrained by lack of investments and funding (IEA *et al.*, 2025).

Figure 3 Distribution of charcoal revenues in Malawi (A) and Kenya (B)



Source: (Zulu and Richardson, 2013).

A third consideration when assessing economic benefits is the national value of the charcoal trade. Claims have been made asserting that the value of the charcoal trade is equivalent to that of the tea sector and that it employs as many people as the educational sector in Kenya; that it produces revenue (worth USD 650 million) that is 5.8 times more than the combination of the tea and coffee industries in the United Republic of Tanzania (Chidumayo, 2019); and that it generates more income for local people when compared with groundnut, cocoa and palm oil in parts of Nigeria (Nyarko *et al.*, 2021).

On a national scale, equating charcoal to regulated sectors like tea and coffee should be done with caution. Questions about who benefits and by how much (addressed above) become relevant, given the negative environmental impacts of charcoal production and use whose consequences (which include unavailability of fuelwood) often impact the poor the most. In most cases, charcoal in Africa does not attract government revenue like other commodities whose economic contribution has been compared to charcoal. Similar to other illegal businesses, significant income can be generated by charcoal production, but this income is derived by a few private individuals, with no benefit to the public. According to the World Trade Organization (Jay, 2024), illicit trade significantly harms societies, stifling economic growth and development. Such activities undermine legitimate businesses, foster corruption and deprive governments of crucial tax revenue needed for societal investments. For instance, illegally traded charcoal could pose unfair competition to legally traded fuels that may generate similar socio-economic benefits, in addition to access to cooking energy.

Finally, concerns about issues such as child labour and physical injury have been raised in some studies (Idowu *et al.*, 2023; Nyarko *et al.*, 2021) and require further assessment in terms of their prevalence. One study (Ocen *et al.*, 2024) found that charcoal production workers were adversely affected by occupational hazards associated with the industry, including physical injuries from handling the feed stock and final product and exposure to chemicals emitted during the charring process. Producers have been reported to suffer from physical abuse at the hands of armed forest-patrol teams who sporadically impound their charcoal and bicycles, impacting their economic, physical and emotional well-being (Zulu, 2010). According to the producers interviewed in that study, they stayed in charcoal production and trading out of desperation.

Also noted by Zulu (2010) are the social impacts of charcoal production and trade, which can heighten the voicelessness of vulnerable groups – especially female-headed households – due to gender-based divisions of labour in the charcoal market and the resulting implications for energy security. Differences in the legality of charcoal trading further contribute to corruption, exploitation, arbitrary increases in transaction costs, and the marginalisation of women and low-income households.

Summary

A major area for research is the role of charcoal in a just energy transition. This has not been investigated in detail, as has been done with other energy carriers such as coal. Given the high dependence on charcoal by millions of people as a primary or secondary source of livelihood, placing restrictions on or seeking to eliminate the sector for environmental and climate protection would not realise a just and fair transition.

CHARCOAL AS A POTENTIAL BARRIER TO CLEAN FUEL TRANSITION

Although not considered *a priori*, a range of perspectives were identified that appear to perceive the wide availability of charcoal as a limiting factor for the transition to cooking solutions that are higher up the energy ladder, such as LPG. A policy response that restricts the use of charcoal would thus pave the way for a modern energy transition. Alternatively, from another point of view, a policy position that supports charcoal sector development impedes the realisation of the modern cooking energy transition. This perspective also aligns with implicit policy positions taken by various development partners who on the one hand acknowledge that charcoal is here to stay, and on the other hand take strong policy positions against supporting charcoal and biomass (*e.g.* in research and funding).

Some authors have suggested that the adoption of an intermediary technology can slow the adoption of an even more improved technology (Armitage, 2022; Hornbeck *et al.*, 2024). Others have shown some shift towards kerosene and LPG when charcoal availability was restricted through bans and other measures (Doggart *et al.*, 2020). Yet another set of studies shows that households adapt to increases in kerosene, cooking gas and electricity prices by shifting to charcoal (Shupler *et al.*, 2023; Wekesa *et al.*, 2023). Collectively, the results of these studies could be taken to imply that in the absence of charcoal, households would have no choice but to transition to these alternatives.

Such studies are, however, isolated. The shifts they report tend to be temporal and mostly confirm consumer sensitivity to cooking energy prices. Over the long term, most studies show income levels to be the main driver of the cooking fuel transition, with increasing incomes correlated to the use of cleaner fuels (Nyarko *et al.*, 2021). This is not surprising given the large price difference between biomass and alternative fuels. Increasingly rising prices of charcoal may render clean fuels more affordable. However, the supply chain barriers, high upfront costs and behavioural factors continue to make the transition impossible for the majority of households.

The theoretical underpinning of the transition away from charcoal to modern fuels is the “energy ladder” (van der Kroon *et al.*, 2013) concept. This concept may hold true in certain respects (a high income enables the affordability of higher-grade fuels) but not in others. This is particularly the case in SSA, where a “fuel stacking” phenomenon is more observable than fuel switching. In fuel stacking, rising incomes confer the ability to purchase additional fuel that is used in combination with traditional fuels like charcoal. Fuel stacking is influenced by charcoal's relative price and availability, cultural preferences, and other reported benefits (Ochieng *et al.*, 2020). Those with high incomes may also consume more charcoal rather than switch away from it, as was reported in Uganda (Bamwesigye *et al.*, 2020). In one study, the adoption of an improved charcoal stove did not meaningfully affect the adoption of other modern cooking technologies such as LPG, bioethanol or electric stoves (Ashagrie *et al.*, 2024).

The fuel stacking concept does not however disprove the finding that charcoal is a higher-grade fuel relative to firewood; hence, it is used more by people in higher income segments than those who are dependent on firewood as primary cooking fuel. This also explains the rural-urban disparity in its consumption. While most charcoal production occurs in rural areas, most consumption occurs in urban areas because the rural people who produce it cannot afford to use it. The high demand in the cities where the price is high means that the producers prefer to sell the charcoal for income rather than consume it.

The arguments above help to illustrate that many people using charcoal would not be able to transition to alternatives unless their cost is drastically reduced. Such drastic cost reductions are not expected because they would require heavy subsidies to sustain them. The existing trends show the contrary: a move away from the subsidisation of cooking fuels, with countries that had implemented them in the past now struggling to maintain them (Rose *et al.*, 2022). Any interventions in charcoal are therefore not likely to impede the transition to cleaner fuels, according to the dominant energy transition point of view.

3. FIELD STUDY IN KENYA

STUDY CONTEXT

In Kenya, charcoal meets more than 70% of the domestic energy demand for cooking. In Nairobi alone, 86% of households use charcoal for cooking (Ndegwa *et al.*, 2021). Consumption extends beyond households into businesses and institutions such as hotels and schools. This usage is projected to increase significantly with population growth and urbanisation.

The charcoal value chain also contributes significantly to income for wood producers, charcoal producers, transporters, brokers, wholesalers and retailers. The sector involves over 600 000 participants. Of these, approximately 250 000 are producers from whom about 2.5 million people get livelihood support (Kamwilu *et al.*, 2021). Despite its significance, the sector largely operates informally.

The majority (40-75%) of the charcoal is produced in arid and semi-arid lands (Ndegwa *et al.*, 2021). As these are fragile ecosystems, the impact of extensive charcoal harvesting is significant not only for the ecosystems and biodiversity but also for the rural populations whose livelihoods depend on these ecosystems. For example, the Kajiado wildlife migration corridor, a vital dispersal area for elephants and other wildlife moving between Amboseli National Park and Masai Mara National Reserve, has been impacted considerably by illegal charcoal burning.

Over the past 20 years, Kenya has tried unsuccessfully to regulate the charcoal industry. In 2025, a law was proposed that would not allow any person to engage in commercial production of charcoal without a valid charcoal production licence issued by their respective county government. For licensed operators, the charcoal bags or sacks must be labelled with the name and address of the charcoal producer, the area and county of production, the weight, the tree species from which the charcoal was made, and the technology used for charcoal production. This, however, mirrors previous laws that have had similar provisions and have failed to curb the illegal trade in charcoal.

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Between 2000 and 2009, the government of Kenya, through the Ministry of Forests and Wildlife and the Ministry of Energy, formulated policies and legislation governing the production, transportation and trade in charcoal. These were contained in Forests Act No. 7 of 2005, Section 59, which became gazetted as The Forest (Charcoal) Rules, 2009. It required commercial producers to register as members of a charcoal producer association (CPA), through which they would acquire a production licence from the Kenya Forestry Services. Transporters were in turn required to have movement permits, and traders to keep records of the sources of their charcoal. Implementation of these rules failed (due to inconsistent enforcement and corruption, among other reasons) (Clube *et al.*, 2024), leading the government to implement bans on charcoal, which have also been largely ineffective.

In 2013, Kenya's National Environment Policy followed with a wide range of measures to promote sustainable management and use of the environment and natural resources. For charcoal, the proposed measures included afforestation programmes, efficient kilns, and awareness and behaviour change. However, very little occurred in terms of implementation.

The Charcoal Rules and Regulations, 2015 restricted areas of charcoal production to land provided by the government. Private landowners had to get a license to produce charcoal for commercial purposes or to produce more than three bags for personal use. Since distinguishing whether charcoal has been produced from government or private land is impossible, implementation of these rules failed.

In 2016, two additional efforts were made to regulate charcoal with limited success: the Forest Charcoal Rules and the Forest Conservation and Management Act (Act No. 34).

Following the failure of these measures, in 2017 the government issued a national charcoal ban, making it illegal to cut trees for charcoal from public and community forests. This ban was renewed in 2018. The bans prohibited the production and transportation of charcoal in the country and across counties within the country but did not restrict production for local use. Since the use of charcoal remained legal, and there were no interventions to restrict the demand for it in major urban centres, locally produced charcoal was still able to move across county boundaries into areas with high demand. The frequent and inconsistently applied charcoal bans since 2018 have left many actors unsure about the current legal status.

FIELD METHODS

This study employed a qualitative research design to investigate the roles of charcoal producers, sellers and users. The aim was to gain insights into the socio-economic, environmental and cultural factors that influence charcoal production, trade and consumption. To achieve this, semi-structured interviews were conducted with a random sample of 108 respondents from Isiolo and Baringo counties, focusing on producers, sellers and users of charcoal. The target population for this study includes individuals engaged in charcoal production, charcoal selling and charcoal use in the two regions. Given the diversity of the population in terms of gender, education level and location (urban vs. rural), a stratified purposive sampling approach was used to ensure that each group is represented appropriately in the study. The sample distribution was as follows:

- **Charcoal producers**: 60 individuals
- **Charcoal transporters:** 23 individuals
- **Charcoal sellers:** 25 individuals
- **Charcoal users:** 95 individuals (derived from the total sample of 108 individuals).

These categories were further stratified by gender, education level and location (urban *vs.* rural) to ensure a balanced representation of different demographic factors that could influence the charcoal trade and consumption patterns in the two regions.

RESULTS

Characteristics of respondents

About 85% of the producers reported that charcoal was a key source of income, often combined with farming or other economic activities. A third of respondents fell below the poverty line (USD 2.15/day), with more producers falling into this category than transporters or retailers. The producers cited a lack of alternative sources of income and the limited investment required, besides time, as motivations for engaging in charcoal production. Among the producers, less than 20% perceived it as profitable or as a main source of income.

Most respondents had primary and secondary school educational levels, with only a few (12%) achieving tertiary level education. Producing charcoal did not require specialised skills, according to respondents. One could learn through observation of the practice, although many reported learning it from others, including close family members.

Actors in the value chain

The actors in the value chain were consistent with reports in other studies, as depicted in Figure 4.

Figure 4 The charcoal value chain as depicted in Isiolo and Baringo counties, Kenya

A mix of local and non-local producers operate under different production models. On the production side are producers who are either contracted or acting on their own, landowners, and local chiefs or government officers that authorise the harvesting of trees for charcoal.

Two dominant models were observed. In the first model, landowners sell the trees to a charcoal broker, who brings in a team to fell the trees, produce charcoal and pay them for the service. The broker then takes the charcoal produced and organises its transportation to the market. This model resulted in highly disproportionate revenue, with landowners and tree cutters receiving less than 20% of the final revenue from the charcoal sale (estimated as the final sale price of a bag of charcoal when it lands in urban markets). A second model consists of charcoal production occurring on public land or protected areas, such as wildlife conservancies. This model is like the first, except for land ownership, and leads to higher revenue for the brokers since they do not pay for the trees.

Once charcoal is produced, it is transported to urban centres. Transporters were often engaged in other transport businesses (*e.g.* transporting passengers), with charcoal transport providing supplementary income. Transportation was often their sole activity in the charcoal value chain, with a few exceptions (23%) where the transporter was also involved in wholesaling.

When the charcoal reaches urban centres, it is sold to wholesalers, who then sell to retailers and vendors, who in turn sell to end users.

Government oversight was reported as absent among those interviewed. Tree harvesting is not allowed in protected areas (*e.g.* wildlife conservancies), yet some of those interviewed reported these areas as their sources of charcoal feedstock. Due to a limited number of rangers guarding the forests, these producers were able to access the forests and cut trees to produce charcoal. Access at times entailed making unauthorised payments.

In some sites, the presence of NGOs was reported. These organisations were supporting various measures, such as improved kiln technology, branding and capacity building.

Sources of charcoal

Fewer than one-fifth of respondents (18%) reported sourcing some of their wood from forest/rangeland (public land), with the rest reporting that the charcoal is derived from land cleared for agriculture (51%) and fallow land (29%). This finding challenges the view that charcoal production is a primary driver of deforestation. Most respondents reported that there were no legal restrictions or permissions needed to access the trees for charcoal production. There could however be bias in such reporting since there is no clarity on whether the charcoal ban is in effect in some of the counties. Participants may have therefore feared reprisals if they reported harvesting on communal land without authorisation. Preferred species were reported to be *Acacia* and *Commiphora*.

Those respondents sourcing charcoal from both private and public land did not apply any tree management practices. The reasons given for this included a lack of seedlings, lack of knowledge and lack of ownership of the land. Only 23% of respondents reported that they owned the land from which they sourced their charcoal. The distance from respondents' homes to the production sites averaged 5 kilometres, which is consistent with other studies' findings.

Production dynamics

Most charcoal is produced using traditional kilns, which are typically located close to the production site (within 500 metres). Producers generally fell the trees themselves using basic tools such as hand-held axes, with only a small proportion (about 15%) hiring chainsaw operators – usually due to the low profit margins that make such services unaffordable.

Once a production site is selected, the process follows several stages, consistent with what has been reported in Ghana (Mutta *et al.*, 2021):

- preparing tools and equipment
- harvesting – felling trees, cutting them into approximately 2-metre pieces and allowing the wood to dry for around two weeks
- carbonisation – setting up the kiln, arranging and covering the wood with soil and grass, placing stones around it, initiating and monitoring the carbonisation process, and cooling
- packaging and sale – removing the charcoal from the kiln, bagging it, and contacting buyers for sale and delivery.

Financial investments in charcoal production are relatively low. Direct expenses – including tools and empty bags – represent less than 10% of the producer's price. Hand tools, such as pangas (machetes), axes, spades, rakes and jembes (hoes), are purchased at a moderate cost and typically last three to five years. Some tools are owned, while others are borrowed from neighbours, occasionally for a small fee. The production process also consumes grass, sand, animal dung (for kiln preparation) and empty bags for packaging. The primary input is labour and the knowledge required to carry out each step.

The production is labour intensive, as has been documented in previous studies (World Bank, 2022). Three-quarters of the time is spent cutting and preparing wood for charcoal production.

Transportation

Most transportation occurs at night to avoid police checkpoints, targeting markets in urban centres. Very few sales occur locally. Once the charcoal reaches urban centres, with Nairobi the most targeted market, it is taken to a charcoal depot from where it is distributed to various locations. Several police roadblocks are encountered on the way but do not restrict the movement of charcoal to its destination. It does, however, impact on the eventual price, as the money paid in bribes is transferred to consumers.

Market dynamics

Most charcoal sales occur at the production site, although it can also be sold at the roadside, in homes or within villages. Producers mainly sell to intermediaries who handle transportation and wholesale distribution, with households, restaurants, schools and other food businesses as target consumers.

Prices vary by points of sale. A 90 kg bag sells for KES 500-900 (Kenyan shillings) (USD 4-7) at the production site, but fetches around KES 2 500 (USD 19) in Nairobi. The city's charcoal market operates largely as a "grey market" where it is no longer possible to distinguish between legally and illegally produced charcoal (*i.e.* derived from protected areas).

Socio-economic impacts

Kenya's charcoal industry plays a significant role in the national economy, employing approximately 700 000 people and generating over USD 427 million annually. According to the Ministry of Environment and Forestry, the charcoal trade was the largest informal-sector employer in 2016, supporting 700 000 workers who in turn provided for an estimated 2.3 to 2.5 million dependents.

Interviews with producers revealed that income from charcoal is essential but rarely sufficient to cover all household needs, leading many to rely on additional sources of income. Only a few depended on charcoal as their primary livelihood, and those who did had typically been in the trade for less than six months. A previous study in Kenya (Mutta *et al.*, 2021) reported that the net income of a typical charcoal producer was below USD 2 per day, despite the work being full-time and leaving little opportunity for other income-generating activities.

Relative to those engaged in charcoal for long durations (ten years plus, 15%) most respondents, especially those in the younger age brackets, were engaged in it opportunistically (due to poverty and lack of jobs). Introducing alternative livelihood sources in rural areas would help deter youth from going into charcoal production in the first place. In the absence of livelihood alternatives, farmers and rural residents will continue to trade in charcoal out of necessity. Proceeds from charcoal were reported to pay school fees, hospital bills and other household necessities.

Summary

The results of the field study confirm the literature findings that charcoal is an important source of income for several actors, including producers, transporters, wholesalers and retailers. While concerns were raised that the income obtained was marginal and insufficient to meet livelihood needs, none of the respondents downplayed its important role, only decrying the lack of better measures to make it more productive.

The semi-illegal nature of the trade takes revenue away from producers to other actors like police officers and large wholesalers, who may not be as dependent on that income as the producers and who do not pay taxes on that income. If the sector were organised, producers would receive fair prices, and the government would obtain revenue from sales and income tax, creating a win-win scenario. As it is, the unfairness and unpredictability of the illegal taxation make operating in the industry much more challenging for both producers and traders.

The labour demand of charcoal production, which could take away time from other sources of livelihood like agriculture, is another key finding. However, none of the respondents indicated there was competition in time allocation for charcoal production and other activities. Instead, respondents commonly reported a lack of income-generating opportunities – a major gap that charcoal is filling. Many, especially the youth, engage in the charcoal business as an opportunistic activity. Introducing alternative sources of livelihood, as has been widely recommended, could move them away from charcoal. The key challenges are identifying opportunities that offer an entry point as easy as charcoal and accessing a readily available market for the product. It is likely that these challenges are the reasons such recommendations have rarely gone beyond statements. A more plausible solution is to improve the charcoal sector in a way that transforms it from an opportunistic occupation to a full-income generation activity, given the reality of growing energy demand and need for cooking energy solutions.

4. THE ROLE OF CHARCOAL IN THE MODERN COOKING TRANSITION

The prevailing perspective on charcoal is that it is a fuel to transition away from, with no role in a modern cooking energy future. This view in turn forms the basis of policy direction and interventions. All transition scenarios therefore include a phaseout of charcoal and its replacement with alternative fuels such as LPG in the near term and electricity in the long term. Surprisingly, most debates on charcoal focus less on energy provision and more on impacts such as deforestation, land degradation and health. Where socio-economic impacts and livelihood benefits are recognised, they have not held much sway in informing interventions and policies.

The reality, however, is that for a majority of the population in SSA, charcoal will remain the only fuel transition option. Charcoal's important role in meeting cooking energy demand seems neglected. While charcoal is currently able to meet the bulk of energy demand, this will not be the case in the future as the resource rapidly dwindles. This should be a primary policy concern relative to other impacts which, although important, may require more evidence to substantiate, as shown in this report, or for which there may be solutions outside the energy sector.

If the charcoal debate were reframed to focus on meeting demand for cooking energy, tackling the inefficiencies in the current production and utilisation processes would gain prominence. In addition, the controversies surrounding charcoal's impact that have led to the current policy paralysis would be resolved. A new form of cooking energy could thus emerge from what already exists in the form of modern charcoal, which has highly distinctive characteristics from the traditional form (Table 1).

Table 1 Technological interventions for modernising charcoal

AREAS FOR MODERNISATION	TRADITIONAL CHARCOAL	MODERN CHARCOAL	IMPACT
Harvesting	Indiscriminate tree-clearing practices, *e.g.* felling all mature trees	Use of coppices and species with fast regrowth	A reduction of over 40% in the tree cover loss that is currently reported
Carbonisation	Traditional earth-mound kilns	Improved charcoal kilns	An increase of 60–80% in the volumes produced from the same amount of wood
Post-harvest	Land left bare after harvesting; producers move on to new sites	Re-planting with species of rapid coppicing ability *(e.g. Anogeissus leiocarpus)*	A reduction of over 50% in the tree cover loss that is currently reported
End use	Traditional charcoal stoves with low efficiency	Improved charcoal stoves	A reduction of 30–50% in the volume of charcoal consumed, with an equivalent reduction in demand

Such sustainably and efficiently produced charcoal does not exist because its development has not been promoted. Charcoal continues to be perceived as a homogenous fuel regardless of where it is sourced, the efficiency of measures used to convert it from wood to fuel, and the efficiency of the technology used to burn it. Improvements in efficiency at end use through improved cookstoves can realise an up to 40% reduction in the quantities of charcoal used to fulfil the same amount of cooking needs. Improvements in the efficiency of kilns used in charcoal conversion can lead to 89% of the wood burned being converted into useful energy (Sieber *et al.*, 2010), potentially reducing wood demand by the same magnitude. Investments in charcoal production through forest plantations, sustainable harvesting practices and post-harvest forest management can render most concerns about forest degradation and deforestation from charcoal use redundant. This efficiently produced charcoal would not only secure the energy needs of millions of people in SSA, but also yield significant socio-economic and livelihood benefits, as well as climate change mitigation.

Energy efficiency is generating a strong global focus among policy makers through recognition of its important role in enhancing energy security and affordability, and in accelerating clean energy transitions. Charcoal use stands out among the key sectors for efficiency improvements, with immediate and significant benefits.

When compared to alternatives like LPG, electricity and other promoted forms of modern cooking energy, modern charcoal (which should be considered to be a distinct product) offers several superior advantages, as shown in Figure 5. Its superiority arises from having a higher ease of uptake since it is widely available, is less cost-prohibitive, requires less behavioural changes due to existing familiarity, and offers energy security relative to alternatives like LPG that are affected by fluctuating global prices and currency devaluations. Charcoal supply chains are well established and highly efficient at meeting demand. Charcoal shortages in urban areas are uncommon and only occur when governments intervene through bans (Mwampamba *et al.*, 2013). Using the same supply chain and actors to introduce a new sustainable energy source therefore has higher chances of success.

COMPARING MODERN CHARCOAL WITH ALTERNATIVES

The Global Bioenergy Partnership (GBEP) provides 24 bioenergy sustainability indicators under three pillars: environmental, social and economic (GBEP, 2020). Adopting the framework with some modifications for relevance to this report, modern charcoal is compared to traditional charcoal currently in use, and to "clean" fuel alternatives. Lower-grade fuels (fuelwood and dung) are excluded, as well as technologies like solar stoves and pellets that have not yet reached significant scale.

The results show that this new fuel source is highly distinct from traditional charcoal and scores favourably against other cooking solutions that are currently benefiting from considerable support. While its environmental score is low compared to other cooking solutions, its social and economic scores are high. This matters because they are necessary to ensure scaled-up adoption and sustained use.

Figure 5 Comparison of modern charcoal with traditional charcoal and clean alternative sources using GBEP sustainability indicators

	INDICATORS	MC/TRADITIONAL CHARCOAL	MC/LPG	MC/ELECTRICITY	MC/ETHANOL	MC/BIOGAS
ENVIRONMENTAL	Lifecycle GHG emissions	Positive	Neutral	Negative	Negative	Negative
	Soil quality	Positive	Negative	Negative	Positive	Negative
	Harvest levels of wood resources	Positive	Negative	Negative	Negative	Negative
	Emission of non-GHG air pollutants	Positive	Neutral	Negative	Negative	Negative
	Biological diversity in landscape	Positive	Negative	Negative	Neutral	Negative
	Land-use change from feedstock production	Positive	Negative	Negative	Neutral	N/A or unknown
SOCIAL	Allocation of new land for production	Negative	Negative	Negative	Neutral	Neutral
	Change in income	Positive	Positive	Positive	N/A or unknown	Neutral
	Jobs in bioenergy sector	Positive	Positive	Positive	Neutral	Positive
	Unpaid time of women in wood collection	Neutral	Neutral	Neutral	Neutral	Neutral
	Expanded access to MECS	Positive	Positive	Positive	Positive	Positive
	Reduced health burden	Neutral	Neutral	Neutral	Neutral	Neutral
ECONOMIC	Productivity	Positive	N/A or unknown	N/A or unknown	Positive	Negative
	Net energy balance	Positive	N/A or unknown	N/A or unknown	Positive	Negative
	Gross value added	Positive	Positive	Positive	Positive	Neutral
	Training & reskilling workforce	Positive	Neutral	Neutral	Neutral	Positive
	Energy diversity	Positive	Positive	Positive	Neutral	Neutral
	Infrastructure & distribution logistics	Positive	Positive	Neutral	Positive	Positive
	Capacity & flexibility in use of bioenergy	Positive	N/A or unknown	N/A or unknown	Positive	Positive
	Change in consumption of fossil fuels & traditional biomass	Positive	Positive	Positive	Neutral	Positive

● Positive ● Neutral ● Negative ○ N/A or unknown

Note: GHG = greenhouse gases; LPG = liquefied petroleum gas; MC = modern charcoal; MECS = modern energy cooking services.

5. TOWARDS A SUSTAINABLE CHARCOAL FUTURE

To achieve a modern charcoal transition, governments and development partners, among others, must reach a consensus that charcoal is not automatically considered a fuel that must be transitioned away from, as has been posited. In addition, it must be recognised that more evidence may be needed to sustantiate some negative impacts that have been attributed to charcoal. Realising this requires filling important research gaps and wider engagement of key stakeholders in the sector through targeted communication. While this study and similar previous ones have sought to tackle some of the controversies about charcoal, limitations on their scope, depth and design mean that some of the strongly established positions on charcoal may not be put to rest. Several questions remain outstanding and require further investigation; hence, further research is one of the key recommendations arising from this work.

A NEW RESEARCH AGENDA ON CHARCOAL

A body of research is needed that contributes to filling the evidence gaps and tackles misconceptions and controversies that are likely to persist about charcoal's impacts and its role in cooking energy access. Important areas for research include:

- Impacts of the charcoal sector, particularly health impacts that have not been well studied. A clear separation should be made between charcoal and other biomass or solid fuels in such investigations. Research that compares charcoal with alternative fuels on various metrics (economic, social, health, environment) would be particularly helpful in resolving the ongoing controversies.
- Research on charcoal as a modern cooking solution. This study introduced the concept of modern charcoal. Studies are needed that further investigate this concept, such as its affordability relative to other clean fuels, acceptability, market potential (domestic and international) and its impacts across the parameters covered in this report (health, socio-economic, environmental). A clear distinction should be made between this form of charcoal and one produced from a "green charcoal value chain",[7] which puts more emphasis on environmental than energy aspects.
- Analysis of past efforts to promote a sustainable charcoal supply is warranted to derive lessons on what did and did not work. Such research should also attempt to unearth whether the outcomes of those programmes have played a role in shaping the position around a shift away from charcoal.
- Analysis of charcoal from just transition perspective. Such research should uncover what would happen to millions of people whose livelihood is dependent on charcoal if the sector were eliminated. It should also offer a pathway for a just and fair transition that achieves energy transition outcomes while safeguarding livelihoods.

Partnerships between various actors (researchers, academia and policy, *etc.*) and across disciplines are needed to execute the proposed research agenda and to enable the advancement of a sustainable charcoal sector.

[7] *FAO (Dam, 2017) has provided an analysis of measures needed to transform the charcoal from its current unsustainable production and use into a climate-smart cooking energy alternative.*

DEMAND AND SUPPLY-SIDE MEASURES

The controversies, if settled, would pave the way for the execution of some key measures to help improve the charcoal sector (Figure 7). Because the issues are interconnected, cross-cutting technical, policy and regulatory measures should be considered and informed by a comprehensive strategy.

Efficiency in extraction

Nearly all the charcoal produced in tropical countries comes from above-ground tree biomass, meaning that whole trees or significant portions of trees must be felled. Some estimates (Arko *et al.*, 2024) suggest that 800 000 bags of charcoal produced annually leads to the depletion of nearly 400 000 trees. In other words, half the volume of a tree is needed to produce a single bag of charcoal. Arko *et al.* (2024) further estimate that 15.3 square metres of land are required to produce a single bag of charcoal. Targeted interventions at these stages could reduce resource waste, enabling more charcoal to be produced using fewer trees and less land.

Efficiency in carbonisation

Traditional charcoal production is highly wasteful. The efficiency of traditional kilns has been found to be as low as 10%, which means that 90% of the wood biomass is lost during the carbonisation process (Villazón Montalván *et al.*, 2019). The traditional production process also affects forest regeneration, as kiln sites are exposed to extreme heat, slowing recovery compared to surrounding areas. Improved kilns are more efficient, requiring about 0.05 hectares of forest per tonne of charcoal (Kamwilu *et al.*, 2021) – half the land needed for traditional earth kilns – and can also boost profit margins, providing a strong incentive for adoption.

Despite these benefits, most producers continue using traditional kilns due to high capital and maintenance costs; transport difficulties; the limited market value for by-products; and a lack of spare parts, skills and affordable credit. Addressing these constraints could substantially increase sustainable charcoal production.

Post-harvest management

Much of the land used for charcoal production has strong potential for rapid forest recovery, particularly with effective post-harvest management. Training producers in these practices and supporting their adoption through policies and legislation can enhance the sustainability of areas used for charcoal extraction. Resilient species, such as *Anogeissus leiocarpus*, have been identified as suitable for replanting on these sites.

Efficiency in end use

Efficient cookstoves reduce the volume of charcoal consumed and can therefore alleviate the pressure on supply. Factors leading to higher adoption of improved cookstoves, including efficient charcoal stoves, have been extensively studied. Key factors include having quality technologies that are appropriate for users' cooking needs, financing options that allow users to overcome high upfront costs, and awareness and behaviour change regarding the value proposition of such stoves. Economic benefits such as savings in fuel purchase costs have been shown to be more convincing than health and environmental benefits and should therefore be highlighted as a central benefit in behaviour change campaigns.

Alternative sources of feedstock

While most charcoal is still derived from wood, alternative feedstocks such as coconut shells, sawmill residues and crop waste offer viable options. Modern regulations requiring replanting, efficient kilns and taxation could make these alternatives more cost-competitive. Many tropical wood industries generate large volumes of waste that could be converted into charcoal briquettes, providing extra income.

Establishing dedicated woodfuel plantations should also be encouraged to reduce pressure on natural forests. This is especially important in peri-urban areas and wood-deficit regions, where farmers can be incentivised to plant and manage trees specifically for charcoal production.

CROSS-CUTTING MEASURES

Policy and legislative measures

Long-term policies should treat charcoal as a permanent energy source rather than a temporary fuel. Rather than penalising its production or transport, policies should focus on encouraging sustainable practices. This could include measures such as harvest quotas, stumpage fees, tax incentives, voluntary certification schemes, and financing through carbon markets or climate funds.

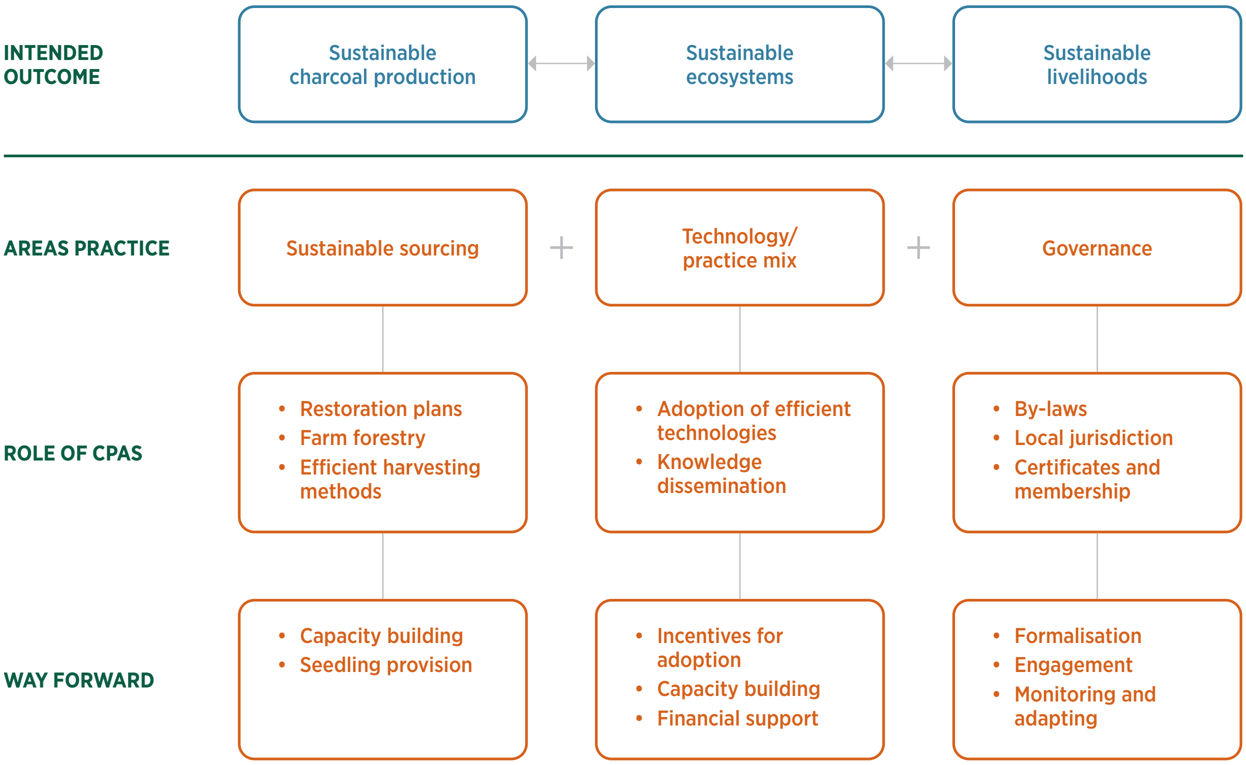
Financing

Financing challenges in the charcoal sector are largely related to covering the costs of forest management interventions and supporting the adoption of improved technologies, including efficient kilns for production and cookstoves for consumption. Capacity-building efforts are also essential to enable these transitions. Innovative financing mechanisms, such as carbon finance and RBF, can be used initially. Over the long term, formalising the sector could generate sufficient revenue to meet financial needs. Differentiated taxation can encourage sustainable sourcing and production, while fees and license revenues can be reinvested in technological improvements. Supportive government policies would further attract investments to scale up improved charcoal-production technologies and establish dedicated wood plantations.

Institutional arrangements

CPAs that have been piloted in Kenya (Kamwilu *et al.*, 2021) and other countries present a great opportunity to actualise sustainability in production, ecosystems and livelihoods, if well supported. Traditional charcoal production tends to be small-scale and dispersed, mainly in rural areas. This makes it difficult to enforce environmental controls. Devolving some of the responsibility for trees and forests through community forest management – accompanied by other measures, such as capacity building and budgetary support to these local institutions – can lead to better control than trying to govern production nationally. Limiting producers to certified producers only can also lead to better control.

Figure 6 Role played by CPAs in Kenya



Source: (Kamwilu *et al.*, 2021).

The charcoal sector should be assigned to a suitable government unit that co-ordinates its production, trade and use. This unit should be supported by a sound institutional framework that includes key players such as charcoal producers, processors and traders; forest and environment officers; trade and licencing teams; and clean cooking co-ordination units, among others.

Data and planning

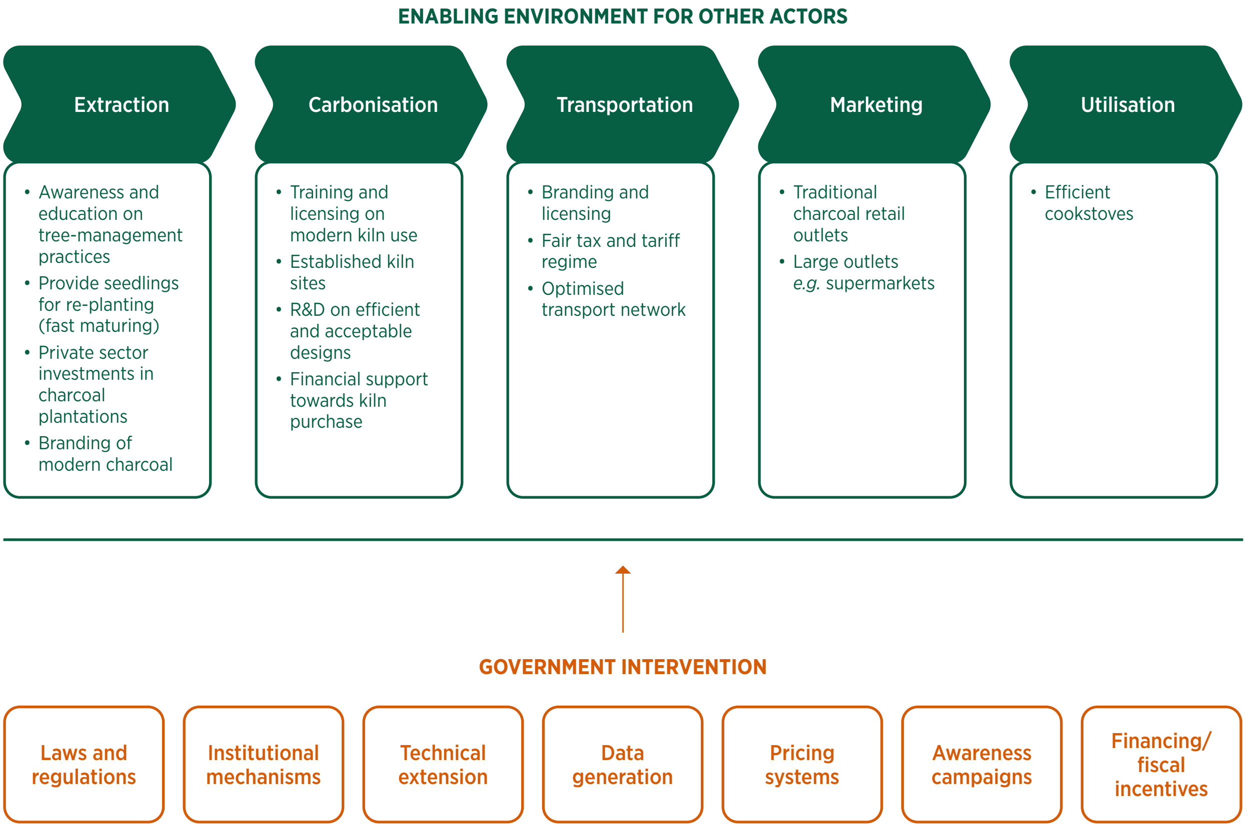
Charcoal production and trade are largely informal and, in some cases, partially banned, making accurate production and consumption data difficult to obtain. As a result, the sector operates in a regulatory blind spot with minimal oversight. The lack of reliable data on the volume and spatial distribution of charcoal production hampers authorities' ability to assess vegetation loss accurately (Sedano *et al.*, 2016) and complicates policy formulation and regulation. Additionally, data on the sector's economic contribution, such as its impact on national gross domestic product, are needed.

Alternative livelihoods for traditional charcoal producers

The high demand for charcoal and the ease of entry into the business provide the greatest incentives for becoming a charcoal producer. In addition, few skills and minimal capital investments are required to enter the business. These incentives are, however, offset by charcoal production's high labour demand and low financial return. These disadvantages mainly arise from the informality of the sector. Providing alternative sources of income could be a solution for the charcoal producers who do not deliberately choose to engage in the charcoal business but do so out of financial necessity.

For the majority of producers who choose to engage in the business, charcoal is an important livelihood source. For these producers, solutions should be found to reconcile the imbalance between the high demand for charcoal and the low financial return for its production. Requiring training and certification in kiln management or mandating the use of efficient kilns, if coupled with training programmes, can achieve a win-win solution both for producers and development objectives. Modern, sustainably produced charcoal could expand the sector's potential to support livelihoods by incentivising government support (*e.g.* in research and development) and private sector investments, as well as by expanding the consumer base locally and internationally (*e.g.* by creating an export product).

Figure 7 A proposed policy framework for modern charcoal



Note: R&D = research and development.

GLOSSARY

Acacia	A tree or shrub that grows in warm climates that bears spikes or clusters of yellow or white flowers and is typically thorny. Also called wattle.
Biomass fuel	Fuel produced directly or indirectly from biomass, such as fuelwood, charcoal, bioethanol, biodiesel, biogas (methane) and biohydrogen. A gaseous, liquid or solid fuel that contains energy derived from a biological source.
Cammiphora	A large genus of East Indian and African trees (family *Burseraceae*) yielding balsamic products.
Charcoal	A dark or black porous carbon prepared from vegetable or animal substances (as from wood by charring in a kiln from which air is excluded).
Clean fuels and technologies	Fuels and technologies that attain the $PM_{2.5}$ and CO levels recommended by WHO. WHO global air quality guidelines for household air combustion (WHO, 2014) provide $PM_{2.5}$ and CO emission rate targets for devices, which are linked to the levels from the air quality guidelines.
Energy ladder	A process by which households, as their income rises, move away from traditional fuels (*e.g.* biomass), first to adopt intermediate fuels (kerosene, coal) and then to use modern fuels (gas, electricity).
Fuelwood	Woodfuel where the original composition of the wood is preserved. Cut and split oven-ready fuelwood used in household wood burning appliances like stoves, fireplaces and central heating systems. Firewood usually has a uniform length, typically in the range 150-500 millimetres.
Modern Energy Cooking Services (MECS)	MECS refers to a household context that has met the standards of Tier 4 or higher across all six measurement attributes of the Multi-Tier Framework for Energy Access (ESMAP, 2015). These include convenience, (fuel) availability (a proxy for reliability), safety, affordability, efficiency and exposure (a proxy for health related to exposure to pollutants from cooking activities).
Prosopis juliflora	An invasive tree species present in arid and semi-arid lands that is native to the rangelands of South America, Central America and the Caribbean.
Unclean or polluting fuels and technologies	Fuels and technologies that do not provide a health benefit. They include unprocessed coal and kerosene, and biomass fuels utilised on stoves that achieve ISO Voluntary Performance Targets (VPT) tiers 0, 1 or 2 for $PM_{2.5}$ and CO emissions (ISO, 2018).

REFERENCES

Abbas, D., *et al.* (2016), "Forestry for a low carbon future: Integrating forests and wood products in climate change strategies", *FAO Forestry Paper. No. 177*, Food and Agriculture Organization of the United Nations, Rome, https://openknowledge.fao.org/items/c60c0a18-bfa5-415d-aa40-c4abe163a403.

Ablo, A. D., *et al.* (2022), "Sacrificing the savannah woodlands for energy and livelihoods? Charcoal production in Ghana", *Energy for Sustainable Development*, vol. 70, pp. 549–59, https://doi.org/10.1016/j.esd.2022.09.001

Ahrends, A., *et al.* (2010), "Predictable waves of sequential forest degradation and biodiversity loss spreading from an African city", *Proceedings of the National Academy of Sciences*, vol. 107/33, pp. 14556–61, https://doi.org/10.1073/pnas.0914471107

Ajibola, A. F., *et al.* (2020), "Policy responses to addressing the issues of environmental health impacts of charcoal factory in Nigeria: Necessity today; essentiality tomorrow", *Communication, Society and Media*, vol. 3/3, pp. p1, https://doi.org/10.22158/csm.v3n3p1

Alfaro, J. F., and Jones, B. (2018), "Social and environmental impacts of charcoal production in Liberia: Evidence from the field", *Energy for Sustainable Development*, vol. 47, pp. 124–32, https://doi.org/10.1016/j.esd.2018.09.004

Amankwah, E. (2019), "Tropical forest: A potential resource for climate change mitigation in Ghana", *International Journal of Environment and Climate Change*, vol. 9/8, pp. 435–42, https://doi.org/10.9734/ijecc/2019/v9i830128

Arko, T., *et al.* (2024), "The multifaceted socio-ecological impacts of charcoal production on the Afram Plains, Ghana", *Trees, Forests and People*, vol. 16, pp. 100586, https://doi.org/10.1016/j.tfp.2024.100586

Armitage, S. (2022), "Technology adoption and the timing of environmental policy: Evidence from efficient lighting", *SSRN Electronic Journal*, https://doi.org/10.2139/ssrn.4108312

Arnold, M., and Persson, R. (2003), "Reassessing the fuelwood situation in developing countries", *The International Forestry Review*, vol. 5/4, pp. 379–83, Commonwealth Forestry Association, Craven Arms, https://doi.org/10.1505/IFOR.5.4.379.22660

Aryal, R. R., *et al.* (2021), "Lessons learned while implementing a time-series approach to forest canopy disturbance detection in Nepal", *Remote Sensing*, vol. 13/14, pp. 2666, Multidisciplinary Digital Publishing Institute, https://doi.org/10.3390/rs13142666

Ashagrie, T. A., *et al.* (2024), "Perception and barriers to improved charcoal cookstoves adoption in Wereta, Ethiopia", *BMC Public Health*, vol. 24/1, pp. 3454, https://doi.org/10.1186/s12889-024-20938-3

Bailis, R., *et al.* (2004), "Impacts of greenhouse gas and particulate emissions from woodfuel production and end-use in Sub-Saharan Africa", Berkeley, CA: Renewable and Appropriate Energy Laboratory, https://rael.berkeley.edu/old_drupal/sites/default/files/very-old-site/OA5.1.pdf

Bamwesigye, D., *et al.* (2020), "Charcoal and wood biomass utilization in Uganda: The socioeconomic and environmental dynamics and implications", *Sustainability (Switzerland)*, vol. 12/20, pp. 1–18, https://doi.org/10.3390/su12208337

Berkouwer, S., and Dean, J. (2023), *Cooking, health, and daily exposure to pollution spikes*, Working paper, No. w31614, National Bureau of Economic Research, Cambridge, MA, https://doi.org/10.3386/w31614

Boucher, D. *et al.* (2011), "The Root of the Problem: What's Driving Tropical Deforestation Today?", Union of Concerned Scientists, www.jstor.org/stable/resrep00075 (accessed 28 August 2025).

Branch, A., *et al.* (2022), "From crisis to context: Reviewing the future of sustainable charcoal in Africa", *Energy Research & Social Science*, vol. 87, pp. 102457, https://doi.org/10.1016/j.erss.2021.102457

Brobbey, L. K., *et al.* (2019), "The economic importance of charcoal to rural livelihoods: Evidence from a key charcoal-producing area in Ghana", *Forest Policy and Economics*, vol. 101, pp. 19–31, https://doi.org/10.1016/j.forpol.2019.01.013

Brouwer, R., and Magane, D. M. (1999), "The charcoal commodity chain in Maputo: Access and sustainability", *Southern African Forestry Journal*, vol. 185/1, pp. 27–34, Taylor & Francis, https://doi.org/10.1080/10295925.1999.9631223

Campbell, B. M. (1996), "The Miombo in transition: Woodlands and welfare in Africa", *CIFOR-ICRAF*, Center for International Forestry Research (CIFOR): Bogor, Indonesia, https://doi.org/10.17528/cifor/000465

Chidumayo, E. N. (2002), "Changes in miombo woodland structure under different land tenure and use systems in central Zambia", *Journal of Biogeography*, vol. 29/12, pp. 1619–26, https://doi.org/10.1046/j.1365-2699.2002.00794.x

Chidumayo, E. N. (2019), "Is charcoal production in Brachystegia-Julbernardia woodlands of Zambia sustainable?", *Biomass and Bioenergy*, vol. 125, pp. 1–7, https://doi.org/10.1016/j.biombioe.2019.04.010

Chidumayo, E. N., and Gumbo, D. J. (2013), "The environmental impacts of charcoal production in tropical ecosystems of the world: A synthesis", *Energy for Sustainable Development*, vol. 17/2, pp. 86–94, https://doi.org/10.1016/j.esd.2012.07.004

Clark, M. L., *et al.* (2013), "Impact of a cleaner-burning cookstove intervention on blood pressure in Nicaraguan women", *Indoor Air*, vol. 23/2, pp. 105–14, https://doi.org/10.1111/ina.12003

Clasen, T. F., *et al.* (2024), *Revisiting the role of LPG in expanding energy access*, Working paper, No. qu5bd, Center for Open Science, https://doi.org/10.31219/osf.io/qu5bd

CLEAN-Air(Africa) (2024), "Preventing carbon monoxide poisoning in African homes", https://cleanairafrica.com/preventing-carbon-monoxide-poisoning-in-african-homes/ (accessed 28 January 2026).

Clube, R., *et al.* (2024), "When punitive approaches fail: Insights into unjust outcomes of Kenya's charcoal policies", Climate Compatible Growth, https://climatecompatiblegrowth.com/wp-content/uploads/When-Punitive-Approaches-Fail-Kenya.pdf

Dam, J. van (2017), "The Charcoal Transition: Greening the Charcoal Value Chain to Mitigate Climate Change and Improve Local Livelihoods", Food and Agriculture Organization of the United Nations, Rome, https://openknowledge.fao.org/handle/20.500.14283/i6935en

Deforce, K., *et al.* (2013), "Selective woodland exploitation for charcoal production: A detailed analysis of charcoal kiln remains (ca. 1300-1900 AD) from Zoersel (northern Belgium)", *Journal of Archaeological Science*, vol. 40/1, pp. 681–9, https://doi.org/10.1016/j.jas.2012.07.009

Dewees, P. A. (1989), "The woodfuel crisis reconsidered: Observations on the dynamics of abundance and scarcity", *World Development*, vol. 17/8, pp. 1159–72, https://doi.org/10.1016/0305-750X(89)90231-3

Dionisio, K. L., *et al.* (2012), "Household concentrations and exposure of children to particulate matter from biomass fuels in The Gambia", *Environmental Science & Technology*, vol. 46/6, pp. 3519–27, American Chemical Society, https://doi.org/10.1021/es203047e

Doggart, N., *et al.* (2020), "The influence of energy policy on charcoal consumption in urban households in Tanzania", *Energy for Sustainable Development*, vol. 57, pp. 200–13, https://doi.org/10.1016/j.esd.2020.06.002

Ellegård, A. (1996), "Cooking fuel smoke and respiratory symptoms among women in low-income areas in Maputo", *Environmental Health Perspectives*, vol. 104/9, pp. 980–5, https://pubmed.ncbi.nlm.nih.gov/8899378/

Ellegård, A., *et al.* (2002), *Charcoal potential in southern Africa: CHAPOSA (Final report)*, pp. 1–44, Stockholm Environment Institute, Stockholm, https://mediamanager.sei.org/documents/Publications/Climate/chaposa.pdf

Ellegård, A., and Egnéus, H. (1993), "Urban energy: Exposure to biomass fuel pollution in Lusaka" (Urban energy and environment in Africa), *Energy Policy*, vol. 21/5, pp. 615–22, https://doi.org/10.1016/0301-4215(93)90044-G

ESMAP (2015), *Beyond connections: Energy access redefined*, ESMAP Technical Report: 008/15, Energy Sector Management Assistance Programme, https://doi.org/10.1596/24368

Ezzati, M., and Kammen, D. M. (2002), "Evaluating the health benefits of transitions in household energy technologies in Kenya", *Energy Policy*, vol. 30/10, pp. 815–26, https://doi.org/10.1016/S0301-4215(01)00125-2

Falcão, M. P. (2008), "Charcoal production and use in Mozambique, Malawi, Tanzania, and Zambia: Historical overview, present situation and outlook" (pp. 1–27), In The Conference on Charcoal and Communities in Africa, June 2008, https://openknowledge.fao.org/server/api/core/bitstreams/14ad8e1b-af18-4ff3-bf54-b89cc1a8453d/content

FAO (2020), "Sustainable charcoal production for food security and forest landscape restoration", in *Twenty-second session, Forests and Wildlife: Africa's diversity for shared prosperity and security*, FO:AFWC/2020/4.2, Africa Forestry and Wildlife Commission, Mpumalanga, South Africa, https://openknowledge.fao.org/server/api/core/bitstreams/14ad8e1b-af18-4ff3-bf54-b89cc1a8453d/content

FAOSTAT (n.d.), "Food and agriculture data", www.fao.org/faostat/en/#home (accessed 28 August 2025).

Fullerton, D. G., *et al.* (2009), "Biomass fuel use and indoor air pollution in homes in Malawi", *Occupational and Environmental Medicine*, vol. 66/11, pp. 777–83, https://doi.org/10.1136/oem.2008.045013

Gabdrashova, R., *et al.* (2021), "The impact on heart rate and blood pressure following exposure to ultrafine particles from cooking using an electric stove", *The Science of the Total Environment*, vol. 750, pp. 141334, https://doi.org/10.1016/j.scitotenv.2020.141334

GBEP (2020), *Global Bioenergy Partnership sustainability indicators for bioenergy: Implementation guide*, Global Bioenergy Partnership, www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/Implementation_Guide/Final_Draft_Implementation_Guide_updated_14.04.2020.pdf

Gill-Wiehl, A., *et al.* (2024), "Pervasive over-crediting from cookstove offset methodologies", *Nature Sustainability*, vol. 7/2, pp. 191–202, Nature Publishing Group, https://doi.org/10.1038/s41893-023-01259-6

Giorgini, P., *et al.* (2016), "Air pollution exposure and blood pressure: An updated review of the literature", *Current Pharmaceutical Design*, vol. 22/1, pp. 28–51, https://doi.org/10.2174/1381612822666151109111712

Girard, P. (2002), "Charcoal production and use in Africa: What future?", *Unasylva*, vol. 53, www.fao.org/4/y4450e/y4450e05.pdf

Herd, A. R. C. (2007), "Exploring the socio-economic role of charcoal and the potential for sustainable production in the Chicale Regulado, Mozambique", A dissertation presented for the degree of Master of Science, University of Edinburgh, https://biblioteca.biofund.org.mz/wp-content/uploads/2019/01/1548675451-Producao%20de%20carvao%20em%20Nhambita%20ARCHerd%20MSc%20Thesis%20_2007_.pdf

Hofstad, O., *et al.* (2009), *How can emissions from woodfuel be reduced?*, (pp. 237–48), Center for International Forestry Research, https://www.cifor-icraf.org/knowledge/publication/3842/ (accessed 28 August 2025).

Hornbeck, R., *et al.* (2024), "Gaining steam: Incumbent lock-in and entrant leapfrogging", Working Paper, National Bureau of Economic Research, https://doi.org/10.3386/w32384

Hosier, R. H., and Dowd, J. (1987), "Household fuel choice in Zimbabwe: An empirical test of the energy ladder hypothesis", *Resources and Energy*, vol. 9/4, pp. 347–61, https://doi.org/10.1016/0165-0572(87)90003-X

Idowu, O. S., *et al.* (2023), "Health risks associated with the production and usage of charcoal: A systematic review", *BMJ Open*, vol. 13/7, pp. e065914, https://doi.org/10.1136/bmjopen-2022-065914

IEA (2023), *A vision for clean cooking access for all*, International Energy Agency, Paris, www.iea.org/reports/a-vision-for-clean-cooking-access-for-all (accessed 1 December 2025).

IEA, *et al.* (2025), *Tracking SDG7: The energy progress report 2025*, International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, the World Bank and World Health Organization, Geneva, www.irena.org/Publications/2025/Jun/Tracking-SDG-7-The-Energy-Progress-Report-2025

IRENA (2024), *Advancing renewables-based clean cooking solutions: Key messages and outcomes*, International Renewable Energy Agency, Abu Dhabi, www.irena.org/Publications/2024/Mar/Advancing-renewables-based-clean-cooking-solutions-Key-messages-and-outcomes

Isese, M. O. O. (2019), "Charcoal production: A promoter of deforestation in Nigeria", *World News of Natural Sciences*, vol. 27, pp. 1-10, EISSN 2543-5426, www.worldnewsnaturalsciences.com/wp-content/uploads/2019/09/WNOFNS-27-2019-1-10-1.pdf

ISO (2018), "Clean cookstoves and clean cooking solutions — Harmonized laboratory test protocols — Part 3: Voluntary performance targets for cookstoves based on laboratory testing", ISO/TR 19867-3:2018, https://www.iso.org/standard/73935.html (accessed 28 August 2025).

Jay, T. (2024), "WTO highlights impact of illicit trade on economic growth and public health", *Global Trade Magazine*, www.globaltrademag.com/wto-highlights-impact-of-illicit-trade-on-economic-growth-and-public-health/ (accessed 28 January 2026).

Kalumiana, O. J. (2000), "Charcoal consumption and transportation: Energy sub-component of the Zambia CHAPOSA study", In Second CHAPOSA Annual Workshop, Discussion at the Second CHAPOSA Annual Workshop, Morogoro, Tanzania.

Kammen, D. M., and Lew, D. J. (2005), *Review of technologies for the production and use of charcoal*, Renewable and Appropriate Energy Laboratory Report, Energy and Resources Group & Goldman School of Public Policy University of California, Berkeley, https://rael.berkeley.edu/old_drupal/sites/default/files/old-site-files/2005/Kammen-Lew-Charcoal-2005.pdf

Kamwilu, E., *et al.* (2021), "The potentials and challenges of achieving sustainability through charcoal producer associations in Kenya: A missed opportunity?", *Sustainability*, vol. 13/4, pp. 2288, https://doi.org/10.3390/su13042288

Kazeem, Y. (2020), "Africa's population will triple by the end of the century even as the rest of the world shrinks", *World Economic Forum*, www.weforum.org/stories/2020/07/africa-population-triple/ (accessed 1 December 2025).

Khalifa, K. O., and Aworry, A. (1982), "Energy from the Sudan forests: Wood for the people", *Seminar on Afforestation in Rural Development in Eastern Africa*, Environment Liaison Centre, Nairobi.

Kirimi, M., *et al.* (2023), "Cleaner cooking with charcoal in Kibera informal settlement in Nairobi, Kenya, and its implications for livelihoods and the environment", *Energies*, vol. 16/19, pp. 6808, Multidisciplinary Digital Publishing Institute, https://doi.org/10.3390/en16196808

van der Kroon, B., *et al.* (2013), "The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis", *Renewable and Sustainable Energy Reviews*, vol. 20, pp. 504–13, https://doi.org/10.1016/j.rser.2012.11.045

Kumar, N., *et al.* (2021), "Do improved biomass cookstove interventions improve indoor air quality and blood pressure? A systematic review and meta-analysis", *Environmental Pollution*, vol. 290, pp. 117997, https://doi.org/10.1016/j.envpol.2021.117997

Lee, D. T. S., *et al.* (2002), "Burning charcoal: A novel and contagious method of suicide in Asia", *Archives of General Psychiatry*, vol. 59/3, pp. 293–4, https://doi.org/10.1001/archpsyc.59.3.293

Legonda, I., *et al.* (2013), "Carbon monoxide exposure during cooking in households: A case of Dar es Salaam City, Tanzania", *Journal of Environmental Science and Engineering,* A 2, pp. 31-35, ISSN 1934-8932, https://www.academia.edu/76347376/Carbon_Monoxide_Exposure_during_Cooking_in_Households_A_Case_of_Dar_es_Salaam_City_Tanzania

McCracken, J. P., *et al.* (2007), "Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among Guatemalan women", *Environmental Health Perspectives*, vol. 115/7, pp. 996–1001, https://pmc.ncbi.nlm.nih.gov/articles/PMC1913602/

McGranahan, G. (1993), *Environmental problems and the urban household in the Greater Accra Metropolitan Area (GAMA) – Ghana*, (p. 126), Stockholm Environment Institute, Stockholm, www.sei.org/publications/environmental-problems-urban-household-greater-accra-metropolitan-area-gama-ghana/ (accessed 24 September 2025).

Medina-Alcaide, M. Á., *et al.* (2015), "Lighting the dark: Wood charcoal analysis from Cueva de Nerja (Málaga, Spain) as a tool to explore the context of Palaeolithic rock art", *Comptes Rendus Palevol*, vol. 14/5, pp. 411–22, https://doi.org/10.1016/j.crpv.2015.03.010

Minten, B., *et al.* (2013), "Forest management and economic rents: Evidence from the charcoal trade in Madagascar", *Energy for Sustainable Development*, vol. 17/2, pp. 106–15, https://doi.org/10.1016/j.esd.2012.08.004

Monela, G., *et al.* (2007), *Socio-economics of charcoal extraction in Tanzania: A case of eastern part of Tanzania*, CHAPOSA, Charcoal Potential in Southern Africa, https://www.suaire.sua.ac.tz/handle/20.500.14820/1365

Msuya, N., *et al.* (2011), "Environmental burden of charcoal production and use in Dar es Salaam, Tanzania", *Journal of Environmental Protection*, vol. 02/10, pp. 1364–9, https://doi.org/10.4236/jep.2011.210158

Mugo, F., and Ong, C. (2006), *Lessons from eastern Africa's unsustainable charcoal business*, World Agroforestry Centre, Nairobi, https://www.worldagroforestry.org/publication/lessons-eastern-africas-unsustainable-charcoal-business

Mutta, D., *et al.* (2021), "Sustainable business models for informal charcoal producers in Kenya", *Sustainability*, vol. 13/6, pp. 3475, https://doi.org/10.3390/su13063475

Mwampamba, T. H., *et al.* (2013), "Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries" (Special Issue on Charcoal), *Energy for Sustainable Development*, vol. 17/2, pp. 75–85, https://doi.org/10.1016/j.esd.2013.01.001

Nakora, N., *et al.* (2020), "Indoor air quality in rural Southwestern Uganda: Particulate matter, heavy metals and carbon monoxide in kitchens using charcoal fuel in Mbarara Municipality", *SN Applied Sciences*, vol. 2/12, pp. 2037, https://doi.org/10.1007/s42452-020-03800-0

Naughton-Treves, L., *et al.* (2007), "Burning biodiversity: Woody biomass use by commercial and subsistence groups in western Uganda's forests", *Biological Conservation*, vol. 134/2, pp. 232–41, Elsevier, https://doi.org/10.1016/j.biocon.2006.08.020

Ndegwa, G., *et al.* (2020), *Charcoal value chains in Kenya: A 20-year synthesis*, Working Paper, World Agroforestry Centre (ICRAF), Nairobi, https://doi.org/10.5716/WP20026.PDF

Ndegwa, G., *et al.* (2021), *The charcoal value chain in Kenya: Actors, practices and trade flows in selected sites*, World Agroforestry Centre, Nairobi, https://hdl.handle.net/10568/115414 (accessed 28 August 2025).

Norconsult Tanzania Limited (2002), "The true cost of charcoal: A rapid appraisal of the potential economic and environmental benefits of substituting LPG for charcoal as an urban fuel in Tanzania", https://coastalforests.tfcg.org/pubs/NORConsult_charcoal_vs_LPG.pdf

North, C. M., *et al.* (2017), "Cooking fuel and respiratory symptoms among people living with HIV in rural Uganda", *ERJ Open Research*, vol. 3/2, pp. 00094, https://doi.org/10.1183/23120541.00094-2016

Nyarko, I., *et al.* (2021), "Socio-economic analysis of wood charcoal production as a significant output of forest bioeconomy in Africa", *Forests*, vol. 12/5, https://doi.org/10.3390/f12050568

Nyarko, K., *et al.* (2023), "Drivers and challenges of off-grid renewable energy-based projects in West Africa: A review", *Heliyon*, vol. 9/6, pp. e16710, https://doi.org/10.1016/j.heliyon.2023.e16710

Ocen, S., *et al.* (2024), "Unveiling factors influencing choice of clean cooking solutions among households: A systematic review of literature", *Frontiers in Sustainability*, vol. 5, Frontiers, https://doi.org/10.3389/frsus.2024.1452900

Ochieng, C. A., *et al.* (2020), "Household perspectives on cookstove and fuel stacking: A qualitative study in urban and rural Kenya", *Energy for Sustainable Development*, vol. 59, pp. 151–9, Elsevier, https://doi.org/10.1016/j.esd.2020.10.002

Oduori, S. M., *et al.* (2011), "Assessment of charcoal driven deforestation rates in a fragile rangeland environment in North Eastern Somalia using very high resolution imagery", *Journal of Arid Environments*, vol. 75/11, pp. 1173–81, https://doi.org/10.1016/j.jaridenv.2011.05.003

Onakomaiya, D., *et al.* (2019), "Implementation of clean cookstove interventions and its effects on blood pressure in low-income and middle-income countries: Systematic review", *BMJ Open*, vol. 9/5, pp. e026517, https://doi.org/10.1136/bmjopen-2018-026517

Pearson, P. J. G., and Stevens, P. (1989), "The fuelwood crisis and the environment: Problems, policies and instruments", *Energy Policy*, vol. 17/2, pp. 132–7, https://doi.org/10.1016/0301-4215(89)90092-X

Rainforest Alliance (2024), "Deforestation vs. forest degradation—what is the difference and why does it matter?", www.rainforest-alliance.org/insights/deforestation-vs-forest-degradation-what-is-the-difference-and-why-does-it-matter/ (accessed 29 January 2026).

Ribot, J. C. (1993), "Forestry policy and charcoal production in Senegal", *Energy Policy*, 21, pp. 543–85, https://doi.org/10.1016/0301-4215(93)90041-D

Rose, J., *et al.* (2022), "The forgotten coal: Charcoal demand in sub-Saharan Africa", *World Development Perspectives*, vol. 25, pp. 100401, https://doi.org/10.1016/j.wdp.2022.100401

Sana, A., *et al.* (2019), "Primary cooking fuel choice and respiratory health outcomes among women in charge of household cooking in Ouagadougou, Burkina Faso: Cross-sectional study", *International Journal of Environmental Research and Public Health*, vol. 16/6, pp. 1040, https://doi.org/10.3390/ijerph16061040

Schure, J., *et al.* (2019), "Efficacité de la production de charbon de bois en Afrique subsaharienne: Des solutions au-delà de la performance du four [Efficiency of charcoal production in sub-Saharan Africa: Solutions beyond the kiln]", *Bois & Forêts des Tropiques*, vol. 340, https://doi.org/10.19182/bft2019.340.a31691

Sedano, F., *et al.* (2016), "The impact of charcoal production on forest degradation: A case study in Tete, Mozambique", *Environmental Research Letters*, vol. 11/9, pp. 094020, IOP Publishing, https://doi.org/10.1088/1748-9326/11/9/094020

Sedano, F., *et al.* (2022), "Influence of charcoal production on forest degradation in Zambia: A remote sensing perspective", *Remote Sensing*, vol. 14/14, pp. 3352, Multidisciplinary Digital Publishing Institute, https://doi.org/10.3390/rs14143352

Seidel, A. (2008), "Charcoal in Africa: Importance, problems and possible solution strategies", GTZ, Eschborn, https://energypedia.info/images/2/22/Charcoal-in-africa-gtz_2008-eng.pdf

Shupler, M., *et al.* (2018), "Global household air pollution database: Kitchen concentrations and personal exposures of particulate matter and carbon monoxide", *Data in Brief*, vol. 21, pp. 1292–5, https://doi.org/10.1016/j.dib.2018.10.120

Shupler, M., *et al.* (2023), "Rising food/fuel prices from the Russia-Ukraine war: Pay-as-you-go LPG consumption & food security impacts in a Kenyan informal urban settlement", *ISEE Conference Abstracts*, 1, Environmental Health Perspectives, https://www.medrxiv.org/content/10.1101/2023.07.09.23292423v1.full

Shupler, M., *et al.* (2024), "Household concentrations and female and child exposures to air pollution in peri-urban sub-Saharan Africa: Measurements from the CLEAN-Air (Africa) study", *The Lancet Planetary Health*, vol. 8/2, pp. e95–107, Elsevier, https://doi.org/10.1016/S2542-5196(23)00272-3

Sieber, S., *et al.* (2010), "Strategies to use biofuel value chain potential in sub-Saharan Africa to respond to global change / enhancing low-productivity farming in Tanzania and linking to SMEs", *"World Food System — A Contribution from Europe"*, In Tropentag, Zurich, www.researchgate.net/publication/319265961_Strategies_to_Use_Biofuel_Value_Chain_Potential_in_Sub-saharan_Africa_to_Respond_to_Global_Change_Enhancing_Low-productivity_Farming_in_Tanzania_and_Linking_to_SMEs

Smith-Sivertsen, T., *et al.* (2009), "Effect of reducing indoor air pollution on women's respiratory symptoms and lung function: The RESPIRE Randomized Trial, Guatemala", *American Journal of Epidemiology*, vol. 170/2, pp. 211–20, https://doi.org/10.1093/aje/kwp100

Tassie, K., *et al.* (2021), "Socioeconomic and environmental impacts of charcoal production activities of rural households in Mecha District, Ethiopia", *Advances in Agriculture*, vol. 1/6612720, https://doi.org/10.1155/2021/6612720

Taylor, E. T., and Nakai, S. (2012), "Monitoring the levels of toxic air pollutants in the ambient air of Freetown, Sierra Leone", *African Journal of Environmental Science and Technology*, vol. 6/7, pp. 283–92, https://doi.org/10.5897/AJEST12.018

van Uhm, D. P., *et al.* (2022), "Organized forest crimes: Charcoal and timber trade in the Democratic Republic of the Congo", in *The Private Sector and Organized Crime* (pp. 149–62), Routledge, https://doi.org/10.4324/9781003198635-11

UNDP and World Bank (1987), "Urban woodfuel development: Feasibility report", World Bank, https://documents1.worldbank.org/curated/en/908111468758753568/pdf/multi_page.pdf

United Nations (n.d.), "Around 2.5 billion more people will be living in cities by 2050, projects new UN report", *United Nations*, United Nations, www.un.org/en/desa/around-25-billion-more-people-will-be-living-cities-2050-projects-new-un-report (accessed 28 August 2025).

Van der Plas, R. (1995), "Burning charcoal issues", *Energy Issues*, FPD Energy Note No. 1, World Bank Group, https://documents1.worldbank.org/curated/en/478471468742859178/pdf/multi-page.pdf

Villazón Montalván, R. A., *et al.* (2019), "Environmental concerns on traditional charcoal production: A global environmental impact value (GEIV) approach in the southern Brazilian context", *Environment, Development and Sustainability*, vol. 21/6, pp. 3093–119, https://doi.org/10.1007/s10668-018-0177-0

Wekesa, C., *et al.* (2023), "Effects of charcoal ban on value chains and livelihoods in Kenyan coast – Stakeholders' perceptions", *Environmental Development*, vol. 45, pp. 100809, Elsevier, https://doi.org/10.1016/j.envdev.2023.100809

WHO (2007), "Indoor air pollution: National burden of disease estimates", World Health Organization, www.who.int/publications/i/item/WHO-SDE-PHE-07.01rev

WHO (2014), "WHO Guidelines for Indoor Air Quality: Household Fuel Combustion", World Health Organization, Geneva, www.who.int/publications/i/item/9789241548885

WHO (2024), "Household air pollution", World Health Organization, www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health (accessed 1 September 2025).

Woolley, K. E., *et al.* (2020), "Investigating the association between wood and charcoal domestic cooking, respiratory symptoms and acute respiratory infections among children aged under 5 years in Uganda: A cross-sectional analysis of the 2016 demographic and health survey", *International Journal of Environmental Research and Public Health*, vol. 17/11, pp. 3974., https://doi.org/10.3390/ijerph17113974

World Bank (2022), *Analysis of the woodfuels sector in Ghana: With options for demand reduction, supply enhancement, fuel switching and governance changes*, No. AUS0002917, The World Bank, Washington, D.C., https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099200001102313104 (accessed 29 January 2026).

Yevich, R., and Logan, J. A. (2003), "An assessment of biofuel use and burning of agricultural waste in the developing world", *Global Biogeochemical Cycles*, vol. 17/4, Wiley Online Library, https://doi.org/10.1029/2002GB001952

Zulu, L. C. (2010), "The forbidden fuel: Charcoal, urban woodfuel demand and supply dynamics, community forest management and woodfuel policy in Malawi", *Energy Policy*, vol. 38/7, pp. 3717–30, Elsevier, https://doi.org/10.1016/j.enpol.2010.02.050

Zulu, L. C., and Richardson, R. B. (2013), "Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa", *Energy for Sustainable Development*, vol. 17/2, pp. 127–37, Elsevier, https://doi.org/10.1016/j.esd.2012.07.007

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