Review

From crisis to context: Reviewing the future of sustainable charcoal in Africa

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ABSTRACT

Is charcoal a sustainable energy source in Africa? This is a crucial question, given charcoal's key importance to urban energy. In today's dominant policy narrative – the *charcoal-crisis narrative* – charcoal is deemed incompatible with sustainable and modern energy, blamed for looming ecological catastrophe, and demanding replacement. However, an emerging *sustainability-through-formalization narrative* posits that charcoal can be made sustainable – specifically, through formalization of production, trade, markets, and consumption technologies. This represents an important opportunity to go beyond the crisis narrative and to engage productively with charcoal. However, this ascendent narrative also risks misrepresenting the reality of charcoal on the continent and leading to inappropriate policies. The narrative's designation of the African charcoal sector as unsustainable at present obscures charcoal production's diverse and uncertain impacts across the continent; moreover, the association of informality with unsustainability obscures a similarly complex and diverse social reality as well as the ways that social processes and relations of power and inequality determine charcoal's sustainability. We argue that charcoal needs to be considered within its historical, social, and environmental contexts to better understand its present and the emergent pathways to sustainable energy futures. We draw upon research that is raising questions about both the charcoal-crisis and the sustainability-through-formalization narratives to argue for a new narrative of *charcoal in context*. This approaches charcoal as a politically, ecologically, and historically embedded resource, entailing significant socio-ecological complexity across diverse historical and geographical conjunctures, and calling for new agendas of interdisciplinary research with an orientation towards sustainability and justice.

1. Introduction

1.1. Charcoal: a modern fuel?

In the ongoing global effort to "ensure access to affordable, reliable, sustainable and modern energy for all" (SDG7), African states face a pressing challenge: how to address the central place of woodfuel in the continent's energy mix and, especially, the increasing reliance on charcoal for cooking [1–4]. Charcoal is "the major primary source of energy for most urban dwellers" across sub-Saharan Africa [5], used by up to 90% of households in some cities [2]. Charcoal production is expanding at an estimated 3% annually due to increasing urbanization, but also due to growing use in rural areas as people switch away from firewood, the other widely prevalent woodfuel [1,2,6]. The quantities of charcoal are vast: over 30 million tonnes are produced in Africa each year, comprising well over half of global production [2].

Charcoal, however, suffers from a serious image problem: it is widely seen as a dirty and inefficient fuel and as responsible for significant social and environmental harms, in particular deforestation and forest degradation. The charcoal question is thus at the heart of planning for the continent's energy future, and indeed today there is a growing attention to charcoal as a potentially sustainable energy source in national and international policy and research [5,7,8]. While today's increasingly constructive engagement with charcoal is a welcome development, we argue that it requires significant critical consideration if it is to contribute to the development of sustainable and just energy for Africa.

Widespread dependence on charcoal in urban Africa stems from multiple factors. For consumers, charcoal's light weight, high calorific content, and cleaner burning relative to firewood make it an efficient fuel choice, while the low cost of purchasing and maintaining charcoal cookstoves versus LPG or kerosene stoves make it highly accessible [5]. Consequently, there is little sign of permanent movement away from charcoal to other energy sources, notwithstanding announcements of electricity-driven "energy transitions" across the continent. Indeed, the focus on electrification and the conflation of all household energy needs under a single "energy issue" obscure fundamental differences between cooking and heating versus lighting and running appliances. Electrification programs have shown little impact in displacing charcoal at scale, not least due to the high cost of electricity and electric cookers, as well as technical challenges including power failures and load-shedding. In some countries, LPG or natural gas may be more viable alternatives and already represent a significant contribution to urban cooking [1], but even with significant policy interventions, they have been unable to dent charcoal's continued growth [9–11]. More broadly, the very idea of a uniform energy transition away from charcoal may be misleading, as there is little evidence that households move "up the energy ladder" through transitions enabled by fossil fuels, electricity, and other renewables such as biofuels. Rather, households appear to practice "fuel stacking", that is, using charcoal together with other fuels where available [12–15] in ways that are "historically developed, spatially situated, and acquired through socialization" [16] in specific "energy cultures" [17].

Charcoal's firm place in Africa's energy mix results not only from socially entrenched demand, but also from the magnitude of the sector itself. Charcoal production and trade, especially in small quantities, are an attractive opportunity for cash income for rural and peri-urban populations, and millions of people are employed across its value chains [2]. The possibility of significant profits has also assembled powerful political and economic interests around expanding large-scale production [18,19]. Although often lumped together in energy policy discourse and statistics with firewood (and sometimes dung) as a "traditional" biomass fuel, there is little about charcoal that is "traditional" [20]: it is almost entirely commercialized, often produced with mechanized tools and transport, and traded through widespread networks extending across national borders and even beyond the continent [18,21,22]. Charcoal is a key fuel of contemporary urban life, a critical infrastructure throughout Africa [23,24].

1.2. Contesting charcoal narratives

In much of today's national and international energy policy, however, charcoal is cast as being on its way out – and with good riddance. In today's dominant narrative – what we call the *charcoal-crisis narrative* – charcoal is anathema to achieving sustainable and modern energy in Africa: it is a symptom of energy poverty, harmful to economic and social development, and ecologically destructive [20,25,26]. Charcoal's near-ubiquitous and growing use due to population increase and urbanization is decried as a looming, and possibly imminent, ecological disaster due to wood extraction outstripping regrowth, a portrayal that resonates with older Malthusian narratives of a "woodfuel crisis" in Africa driven by population growth amidst dwindling forests [14,27–29]. Charcoal production is often blamed as a "major driver of deforestation" [30]. In Uganda, for instance, it has been asserted that 80,000 ha of forests are being cleared annually for the "unsustainable production of charcoal and timber" and that the country is facing a projected future wood biomass deficit of over 100 million tonnes annually [31].

In this view, charcoal needs to be replaced. In some instances, replacement is framed as an urgent priority for environmental governance, which can lead to repressive bans on production or trade, to the extent of some states launching what can amount to an apparent "war on charcoal" [32]. In other cases, it is omission more than repression that characterizes charcoal policy, revealing assumptions among policymakers that charcoal will gradually be replaced by cleaner and more efficient fuels in a natural transition driven by modernizing economies. Policies to reduce pressure on forests by increasing wood supply through plantations or woodlots and making production, trade, and consumption more efficient have been implemented [14,29,33]; nevertheless, the overall policy context has been characterized as comprising "weak, misguided, neglected, underdeveloped, disjointed, overly prohibitive, contradictory or non-existent woodfuel policies and laws, combined with poor enforcement and regulatory capacity" [5]. In short, as Zulu and Richardson note [5], "Putting too much faith in the 'energy transition' theory has undermined realistic, proactive policy-making on charcoal", while it disregards the challenges to fuel switching, the importance of charcoal income, and the vast economic and political structures that continue to depend upon, support, and profit from the charcoal sector. Whether charcoal-fueled catastrophe is thought to be impending or a distant possibility, and whether one believes charcoal should be stamped out immediately or can be left to dwindle away, the diagnosis is clear: charcoal is inextricably associated with poverty, underdevelopment, and environmental degradation. Ultimately, then, the dominant charcoal-crisis narrative concludes, charcoal simply does not have a future in Africa's modern energy landscape.

In the face of this dominant narrative, however, a significant reassessment of charcoal in Africa has been occurring, as charcoal is increasingly being envisioned as a foundation for sustainable development [5,34,35]. Instead of a problem, charcoal is now often proposed as part of the solution and, rather than on its way out, as part of Africa's long-term energy future. This reassessment is being spurred by the recognition of charcoal's continued importance to household energy, by new research programs developed by a growing community of energy research and policy organizations in the continent and beyond [36], by some donors' growing interest in small-scale, private-sector energy in place of large-scale public infrastructure [37], but perhaps most importantly by today's increasing concern with climate change, greenhouse gas emissions reductions, and sustainability more broadly [38]. Drawing in part on several decades of proposals, investigations, and interventions around the possibility of sustainable wood energy [14,29], a broad new body of research, which we chart below, is exploring the possibilities of charcoal as a sustainable, renewable, and even green

energy source.

Amidst this flourishing of interest in sustainable charcoal, an alternative charcoal narrative has coalesced and begun to take hold, in particular in energy, climate, and forestry policy. We encapsulate this narrative as *sustainability through formalization* – specifically, formalization of charcoal production, market exchange, national and international trade, and consumption. This ascendent narrative is being articulated widely by international organizations, including the African Union, UNEP, FAO and UNDP [2,4,30], bilateral donors [3,39,40], development agencies [3,41,42], and governments, which are increasingly revising or developing new forestry or energy policies and drafting charcoal or biomass energy strategies [43,44]. This emergent narrative of sustainability through formalization retains the assumption, familiar from the crisis narrative, that the present-day charcoal sector is increasingly unsustainable. As the FAO declares in its influential 2017 report on the "charcoal transition", at present "only a small volume [of charcoal] is produced sustainably" [2]. However, the sustainability-through-formalization narrative insists, charcoal's deleterious social and ecological impacts are not an inherent aspect of the sector, perpetuated by an inescapable Malthusian logic. Rather, unsustainability is framed as the contingent, and avoidable, outcome of increasing demand in the context of a largely informal sector. Specifically, blame is placed on a lack of regulation, a lack of enforcement where regulations exist, and deficient organization and governance of the sector; it is also placed on the widespread use of rudimentary, inefficient technologies. Therefore, today's emergent narrative concludes, the key to sustainable charcoal is to remedy these deficits through the formalization of land tenure, forest management, wood supplies, production labor, markets, and trade through the establishment of effective regulations and institutions, and as well as through the formalization of production and consumption technologies via improved kilns and stoves. This broad agenda of greening charcoal through technical regulatory, organizational, and technological interventions is thus presented as the path to ending unsustainable exploitation of forests and woodlands as well as to income benefits for producing communities, lowered emissions, improved government revenues, and cleaner urban cooking – that is, to sustainable development. While some of these elements are familiar from past narratives and policies on charcoal and woodfuel [14,29,45], it is their combination into a coherent, increasingly prevalent, portrayal within national and international charcoal policy, and within the overarching context of global climate change, that represents the novelty of today's emergent sustainability-through-formalization narrative.

The ascent of this new narrative is an important development since it places charcoal at the center of Africa's future energy agenda, representing an auspicious opportunity to go beyond the charcoal-crisis narrative – as well as the often-misaligned policies associated with that vision – and instead to engage constructively with charcoal as part of Africa's energy future. We argue, however, that the ascendent narrative *also* risks misrepresenting the present reality of charcoal on the continent and leading to inappropriate policies. In this article, we draw on research that is raising questions not only about the still-dominant charcoal-crisis narrative, but also about the new sustainability-through-formalization narrative, suggesting that charcoal cannot just be framed as informal and thus unsustainable. Instead, charcoal needs to be considered within relations of power and inequality and within its historical, social, and environmental contexts in order to more deeply understand its present and emergent pathways to charcoal futures that are socially and ecologically sustainable [23,29].

We therefore propose a third charcoal narrative, which we term *charcoal in context*. That is, we approach charcoal as a resource embedded in specific political, ecological, and historical contexts, entailing significant socio-ecological complexity across diverse geographical conjunctures, and calling for new agendas of interdisciplinary research. This does not mean abandoning the emerging narrative of sustainability through formalization, but rather assessing and contextualizing its components and assumptions within a broader

understanding of charcoal as part of environmental, energy, urban, and political histories and geographies [46]. In doing so, we draw upon existing traditions of research in political ecology, human-environment geography, history, environmental studies, energy research, anthropology, development studies, and beyond, seeking to bring these multidisciplinary insights to bear on charcoal. This is a direction towards which important ongoing research on charcoal is pointing the way, as we document below. In short, we argue that today's flourishing of research on the possibilities of sustainable charcoal, as it breaks away from the dominant narrative of charcoal crisis, should not be restricted by an ascendent narrative of sustainability through formalization. This is particularly important as the sustainability-through-formalization narrative becomes increasingly prominent in local, national, and international policymaking, possibly even becoming the new dominant charcoal narrative. Instead, a narrative of charcoal in context can help promote the diversity and complexity of today's charcoal research while pointing in new directions, just as the narrative recognizes the diversity, complexity, and many possible future pathways of charcoal itself.

1.3. Article outline

To support this argument, the article proceeds as follows. Section 2 argues that the new sustainable charcoal narrative's categorical identification of charcoal with accelerating ecological unsustainability – a feature it shares with the dominant narrative it is challenging – obscures a much more diverse and complex reality across the continent, in which charcoal's ecological impact is highly socially mediated and differentiated, and sometimes ambiguous. While sophisticated technologies and methods – especially remote sensing and formal modeling – to determine charcoal's impact upon deforestation and degradation are being developed, these need to be paired with expanded social science research that comprehends charcoal as entwined with complex social structures and processes in order to discern its present and future magnitude and its likely ecological impacts [33,47,48].

Next, in Section 3 we argue that the representation of the charcoal sector as uniformly informal similarly obscures a more complex and diverse reality. The charcoal sector is more appropriately characterized not by a categorical informality but by shifting and dynamic hybrid arrangements of formality and informality, legality and illegality, mechanized technology and basic tools, which are shaped by complex underlying, multi-scalar social processes and structures of power, inequality, and contention [23,33]. That is, the new charcoal narrative tends to obscure the way that complex social processes and relations of power and inequality – rather than a simple informality – determine the sector's sustainability and the possibilities for transforming the sector. Thus, we conclude, the assumption that formalization will necessarily lead to sustainability is misplaced, since an exclusive policy focus on technical regulatory and technological interventions can neglect these existing, ongoing processes and the power-laden social settings in which charcoal is produced, traded, and consumed and with which any policy interventions inevitably become entwined [49].

We develop this argument by exploring four specific aspects of the contexts in which charcoal production, markets and marketing, and trade take place: *land, labor, technology,* and *political authority*. We show how each is characterized not by uniform informality and a deficit of regulation or organization, but by ongoing social processes and relations of power and inequality, which together shape where, how, and by whom charcoal is produced and traded, as well as its ecological impact and, ultimately, sustainability. Each of these four aspects represents an important arena for future research, contributing to the articulation of a narrative of charcoal in context. As we note in the conclusion, as charcoal becomes increasingly prominent in national and international development, energy, and climate policies, such multi- and interdisciplinary research agendas will be crucial in ensuring that those policies bring benefits to, and do not compound the harms already faced by, vulnerable communities and ecosystems. Research will also be needed to

comprehensively map possible futures of charcoal and thus to show the diversity and complexity of pathways to sustainability and justice, beyond the categorical policy demand for formalization.

1.4. Review method

This review article began with a series of presentations given at the April 2019 conference "Rethinking Sustainable Development from Northern Uganda," held in in Gulu, Uganda, and organized by Gulu University, Makerere University, Cambridge University, and the Center for African Research (Gulu). The presenters represented a wide disciplinary reach – including political science, ecosystems science, forestry, bioenergy science, history, geography, and development studies – as well as geographical reach, based in universities and research institutes across Africa and beyond the continent. After the conference, the presentations were turned into short written pieces via an expert elicitation exercise in which each researcher focused on a specific aspect of charcoal – whether as an energy source, a forest product, a commodity, a target for policy interventions, a source of revenue, or otherwise – in order to, from their own experience and expertise, pose broader questions about the sector that they felt required critical attention and could be part of the agenda for future charcoal research. Altogether, the process comprised a multi-disciplinary horizon-scanning exercise that identified key gaps and emerging questions in charcoal research and policy in Africa, arriving at the four key themes of land, labor, technology, and political authority.

This process provided the framework for a purposive narrative literature review, which "can be particularly useful for exploratory reviews that seek to synthesize insights from a variety of perspectives and disciplines" [50]. Accordingly, we engaged literature from a wide range of disciplines, research traditions, and policy contexts. Although narrative reviews are inevitably characterized by a lack of replicability and a risk of bias towards specific authors' area of expertise [50], this risk is mitigated in the present study by the disciplinary breadth of the authors' competence areas across the natural sciences, social sciences, and humanities, as well as their wide geographical extent and their significant research and policy experience from local to international levels. Through the process of the narrative review, we triangulated the charcoal-in-context narrative synthesized from our expert elicitation process vis-à-vis two other narratives identified in the policy and research literature that were subsequently synthesized for the purposes of discussion: namely, the dominant charcoal-crisis narrative and the ascendent sustainability-through-formalization narrative. Overall, the extant literature is characterized by significant complexity, variability, and nuance. However, by distilling these three "ideal type" narratives or general tendencies in charcoal discourse, we enable both triangulation and focused discussion between these broad yet nonetheless recurring positions identified in the literature.

The article thus represents an effort at developing multi-, inter- or trans-disciplinary research agendas, which are becoming of growing importance in energy research [51–54]. That said, the review inescapably neglects aspects of the present and future of charcoal and charcoal research that would surely emerge in other efforts at research agenda-setting. For instance, our review focuses on the production side of the charcoal sector, following value chains as they leave production areas and move towards (mostly) urban consumers. We only briefly mention the very extensive literature on charcoal markets or on household cooking choices, practices, and technologies, all requiring further research. We also do not address questions around emissions accounting nor around the broader methodological dilemmas in charcoal research at the landscape scale. Nevertheless, we hope that our approach and argument might provide ideas or frameworks useful for research on other dimensions of the charcoal sector as well as on other biomass fuels.

2. Situating sustainability

Woodfuel in Africa has been subject to national and international planning since the colonial period, in particular within forestry policy, but it was not until the 1970s that alarming narratives about catastrophic deforestation driven by growing woodfuel demand – a looming "woodfuel crisis" driven by both firewood and charcoal – rose to prominence [14,28,29]. These narratives of the "other energy crisis" (alongside the oil crisis) were soon subject to contestation, as counter-narratives emerged questioning their assumptions, evidence base, and policy conclusions. In the decades since, national and international woodfuel narratives and policies have taken a variety of routes and shown frequent shifts but little sustained or overall coherence [14,29]. In today's focus specifically on charcoal, as noted above, we see another shift from a dominant crisis narrative of charcoal requiring replacement due to its inescapable ecological unsustainability, to an emerging narrative of making charcoal sustainable through formalization. What both narratives have in common, however, is the assumption that, due to increasing use under present conditions of production, marketing, and consumption, charcoal energy is currently unsustainable and an impediment to development.

Just as an earlier generation of research raised questions about the assumptions and conclusions of woodfuel policy, so today research is raising questions – explicitly and implicitly – about whether charcoal production is in fact unsustainable at present, signaling broader challenges to our knowledge about the charcoal sector as a whole. Indeed, there are significant disagreements in the policy and research literature, from continent-wide studies that find "the future of the charcoal sector is not dire" [55], or that "the problem is both less severe and more heterogeneous than is generally acknowledged" [56]; to regional studies that find charcoal unsustainable as the "forest degradation frontier" progresses further [57,58]; to national-level projections of impending collapse, such as Uganda's projected tree biomass deficit of over 100 million tonnes annually [31]. The uncertainty around charcoal is not unique but often reflects more general uncertainties over measuring and modeling forest-related land-cover change and emissions in Africa [56,59–61], as well as uncertainties in modeling of the continent's energy profile. The problems with charcoal statistics are well known – a dearth of ground-based forest inventory data [62,63], a lack of consistency in data even from major organizations, the difficulty of researching a decentralized and often illegal or clandestine sector [20], the tendency for questionable statistics to circulate as established fact [64], and politicized collection and interpretation [65]. While greatly improved data are now being made available through rapidly developing remote sensing technologies, there remain significant conceptual and methodological hurdles.

2.1. Measuring deforestation and degradation

In this sub-section, we explore some of these difficulties around determining charcoal production's responsibility first for deforestation and, second, for forest degradation. As to deforestation, charcoal production's co-presence with other drivers of land-cover change makes determining its precise contribution conceptually and empirically difficult. Studies have made it clear that, when occurring alone, charcoal production seldom leads to permanent land-cover change – that is, to deforestation. This is because, when the sole purpose of tree-felling is charcoal, producers often practice selective cutting of preferred species and sizes, leading to temporary loss of forest cover that is regenerated through regrowth or to longer term forest degradation when conditions for regrowth are suboptimal [20,34,66,67]. It is where production occurs in conjunction with other processes of land-use change, in particular the expansion of agriculture, ranchland, or infrastructure, that charcoal is most associated with deforestation [56,59]. But how much responsibility to attribute to charcoal, and how to determine that responsibility, is challenging: actors themselves may misrepresent their

reasons for land-cover change, as blaming charcoal production for deforestation can be a convenient way of concealing the ecological impact of large-scale farming, infrastructure development [5], or rural modernization programs [25,68]. Conversely, farmers looking to make money from charcoal by removing trees may claim to be legitimately expanding fields. It can sometimes even be a matter of perspective: for example, when charcoal is produced alongside agricultural or urban expansion, production may be interpreted as an incentive for deforestation, as the wise use of biomass waste, or as a byproduct of other primary activities. In those cases where charcoal production can be identified as responsible for clear-cutting, it may still be difficult to determine whether that amounts to deforestation unless long-term monitoring is undertaken [69]. A clear-cut area might be left to regenerate, or it could be converted to agricultural or grazing land; few studies, however, have the longitudinal scope needed to find out. The problem of proximate versus underlying drivers of deforestation also arises [63,70]: even where charcoal production can be identified as a proximate driver of deforestation, there are a wide range of possible underlying social, economic, and ecological drivers that lead to increased pressures or incentives to engage in charcoal production in the first place. If the sustainability-through-formalization narrative tends to emphasize charcoal as a proximate driver of deforestation, the charcoal-crisis narrative recognizes underlying drivers, but tends to favor some (in particular, rural and urban population growth) while downplaying or neglecting others (such as compounding economic growth, income or wealth inequalities, and broader dynamics of capital accumulation or concentration at national or international scales).

All that said, it appears certain that charcoal production, even alone, is indeed leading to deforestation in specific cases [71]. As Chidumayo and Gumbo argue, "although deforestation caused by charcoal appears to be small at national and regional scales, there is no doubt that it can be a serious environmental problem at a local scale" [34], often in what Bailis et al. identify as specific "hotspots" for charcoal production [59]. Furthermore, even if a clear-cut forest may eventually regenerate and thus not amount to deforestation per se, such definitional nuances may be purely academic to communities reliant on disappearing forests for their livelihoods [72].

Two lessons for research can be drawn. First, understanding charcoal's contribution to deforestation requires significant attention to the broader social systems in which charcoal production and trade are embedded – that is, attention both to other proximate drivers that are co-present with charcoal production, as well as to the wide range of possible underlying drivers. Even then, however, precise attribution of charcoal's contribution may sometimes be impossible alongside that of other significant factors, including the expansion of permanent or shifting agriculture, transitions between agriculture and pastoralism, mining, the expansion of human settlements due to sudden migration or displacement, and so on. Second, although crisis narratives of widespread charcoal-driven deforestation may lack a strong empirical basis, charcoal production is incontestably causing significant episodes of harmful local deforestation, and environmental violence more generally, to many communities – and in that respect, addressing the environmental harm of charcoal clearly needs to be at the forefront of environmental policy across a range of contexts.

Charcoal production's direct responsibility for forest degradation through selective cutting is clearer than its responsibility for deforestation, to the extent that some studies have declared charcoal "the main cause of forest degradation" in sub-Saharan Africa [58]. This has taken on increasing prominence with climate change mitigation initiatives, as forest degradation caused by charcoal production has been named a "significant" cause of global greenhouse gas emissions [2], thus pronouncing charcoal to be unsustainable globally as well as locally (although how "significant" a cause it is [56], and whether these survival emissions are "significant" enough to warrant the often invasive response, is another question). With degradation, too, problems arise for determining charcoal production's actual ecological impact and sustainability. Degradation, when measured in terms of change to aboveground woody biomass, has traditionally been much harder to measure through remote sensing than deforestation has been. Today, however, rapid developments in satellite technology and image processing are opening new possibilities for directly measuring forest degradation. These can be combined with the creative use of indirect measures, such as scars from production kilns, to better attribute charcoal's role in forest and woodland degradation [58,73–76].

Yet even with improved measurement technology, assigning responsibility for forest degradation to charcoal production can face similar challenges as the attribution of responsibility for deforestation. Charcoal production often co-exists with other extractive forest activities, such as logging for timber or livestock grazing and with partial forest clearing for agriculture, thus risking over-attributing ecological harm to charcoal [63,69]. Moreover, different cutting, production, and post-harvest management techniques, which may not be discernable via remote sensing, can lead to very different regrowth trajectories. This can also lead to problems of scale: where different production methods coexist side-by-side, the ecological impact and sustainability of charcoal production can vary dramatically from one land parcel to the next, depending on, for instance, whether large-scale semi-industrial production or small-scale livelihood production predominates, leading to different determinations of the overall sustainability of charcoal production at different scales, even in the same region [19]. To label charcoal unsustainable on wider scales may conflate the impact of large producers with subsistence producers, possibly placing undeserved blame for degradation on the latter. Finally, definitional problems also arise for "degradation", which, in Blaikie and Brookfield's classic formulation, is a "perceptual term" [77]: expanding its meaning beyond aboveground woody biomass loss to encompass biodiversity, livelihoods, or "ecosystem services" [57,78–80] renders charcoal's impact even harder to measure consistently and meaningfully, opening the way to contesting and contrasting visions of what comprises a "degraded" landscape or forest. In short, while remote sensing is advancing rapidly to better measure the loss of woody biomass and changes to forest structure in areas of charcoal production, interpreting those data and discerning charcoal's contribution to negative ecological changes requires significant clarification of the social contexts in which production is taking place and critical attention to the concepts and frameworks being used in interpretation [81].

2.2. Modeling charcoal's future

Alongside, and often drawing upon, rapid developments in remote sensing, a new body of sophisticated formal modeling work is seeking to better ascertain charcoal's future in terms of how much is produced and consumed, where it is produced, and what its ecological impact will be [55–57,79,82]. Impetus from climate change mitigation efforts, in particular REDD+, is giving these studies an increasingly prominent role in policy. However, significant discrepancies remain among predictions of charcoal's future sustainability, which stem partly from incomplete and inconsistent data, but also from the different assumptions, scales, and variables used in different modeling exercises. For instance, the future size of the charcoal sector is often modeled as determined by future demand and/or future supply, both of which are often assumed to follow trends in population growth. In these models, Africa's unprecedented urbanization is assumed to drive increasing demand for charcoal [45,55,83], and expanding rural populations, facing land scarcity and poverty, are assumed to take advantage of charcoal's "low entry barriers" and thus increase supply. However, as Iiyama et al. argue, production is "not a simple function of woodfuel demand and supply" [84], and so questions can be raised about both of these assumptions, as well as about the assumed spatial relationship between sources of demand and supply.

First, in terms of demand, while urbanization will clearly be a key factor going forward, possible changes to urban and rural energy use

profiles need to be considered. The IEA has pointed to possible signs of growing diversity in the energy profiles of African cities, with efforts at promoting LPG, natural gas, and electricity along with hydropower projects, grid expansion, and new fossil fuel discoveries [1], but, as noted, there is little sign of these developments leading to lowered charcoal demand. That said, the assumptions behind the equation of urbanization with charcoal use in coming decades may need rethinking, as the shape of urbanization in sub-Saharan Africa, and the energy profiles of those future urban forms, is still being determined [85–87]. Perhaps the most dynamic face of urbanization today is the expansion of smaller regional urban centers and peri-urban areas [88], whose energy use patterns may diverge from existing experiences. Questions include whether smaller size and geographical dispersal may lead to a greater reliance on firewood, or might provide the opportunity for solar, biogas, and renewable cooking technologies both among households and among the small and medium commercial enterprises that are expanding with urbanization [24]. Or, if charcoal continues to predominate, the mode and impact of production may change, as suggested by the divergent value chains found serving small and large urban markets [89,90]. Further complicating dichotomous conceptions of urban/rural are instances of "rurbanization" [91], "extended urbanization", or "new rurality", in which traditionally "urban" consumption patterns, including charcoal use, proliferate amidst rapid change in ostensibly "rural" areas [92]: in Kenya, for instance, an almost equal number of rural as urban households are using charcoal at even higher per capita levels [6]. Finally, the assumption of general and uniform urbanization throughout the continent may not be supported by evidence [86], and even the definition and measurement of urban populations can vary significantly between countries, adding to the uncertainty [93].

Changing patterns to large-scale population displacement due to conflict or ecological pressures may also re-shape the charcoal sector [94–96]. Displaced populations may find themselves suddenly dependent upon charcoal, with firewood inaccessibly located in insecure areas and aid agencies unable to provide alternative cooking means. Rapid expansions of displaced persons' settlements can degrade nearby woodlands and forest, while possibly enabling afforestation of abandoned land, thus setting the stage for future expanded charcoal production [97–99]. The sudden post-conflict demand for charcoal by rapidly expanding cities, such as post-war Juba in South Sudan, can lead to a militarized and ecologically destructive industry [100]. These new and changing urban and rural energy contexts, and their ecological impacts, represent a significant research deficit.

Second, turning to supply, a focus on rural population growth as driving production tends to assume the prevalence of small-scale, informal producers. This can miss the large-scale production of charcoal, whether by major commercial enterprises and contracted work crews or alongside land clearance for other purposes, and thus also miss the possibility that production levels may depend more on business interests, agricultural expansion, or pressures on smallholder farmers to produce commodities for markets than they do on expanding populations [101]. Labor arrangements, value chains, and modes of production can vary dramatically and shift quickly, as can their implications for production levels and ecological impacts, thus demanding close attention to social dynamics. More broadly, research has also questioned the assumption that population growth and poverty lead to a spiral of deforestation, showing that deforestation in some cases "decreases with population density and increases with household assets" [62,102]. Assumptions of linear ecological or social trends can miss out on possible rapid non-linear changes in disturbed ecological systems and possible sudden ruptures in political or social arrangements [103], which can lead to dramatic changes to charcoal use, production or impact [104]. Forest services can be defunded, natural disaster can strike, land given to commercial farmers, local contestations can prevent production, large plantations established, or agroforestry systems set up based around farm-integrated trees and farmer-managed natural regeneration schemes, all leading to very different futures for charcoal.

Spatial assumptions are also often built into models in order to link specific sources of demand with specific implications for sources of supply. For instance, geographical proximity to urban centers and accessibility may be taken as determining where charcoal production will occur, as production is represented as expanding outwards from cities and roads in predictable "ecological footprints", sometimes in distinct "waves" [57,66,105]. However, where charcoal is produced is also highly socially mediated. While wood may indeed often first be extracted from nearby sources and along roads, as charcoal production moves further beyond major cities, and as markets grow, the choice of locations will necessarily be determined by a wider array of factors beyond the geographical proximity of trees—in particular, their social and political accessibility. The rapid expansion of flexible commodity chains, crossing hundreds of kilometers and international borders [106], makes geographical relations between demand and supply even more unpredictable. This is observed, for instance, in the rise of large-scale charcoal production in Uganda resulting from the controversial 2018 logging ban in Kenya [107]. The establishment of Chinese-run charcoal factories in Nigeria for export to East Asia may signal even more intensive extractive pressures on African forests and woodlands as commodity chains reach globally [108], further disconnecting charcoal production levels and locations from changes to demand internal to Africa. There can be shifting disjunctures between sources of demand and sources of supply, making multi-scalar analysis all the more crucial since judgments about the charcoal sector's sustainability can depend on the chosen geographical unit and the assumptions about the length of commodity chains associated with that choice [62].

In short, remote sensing and formal modeling are rapidly adding new rigor and insight to our understanding of charcoal's present and future magnitude and sustainability in Africa. But they are only part of the picture, since the methodological reliance on quantifiable variables and simplified assumptions highlights again the need for complementary research into charcoal's diverse and complex social contexts to better identify variables, clarify assumptions, and probe construct validity, as well as to explore those aspects simply inaccessible to more formal and quantified methods. This is particularly important as remote sensing and formal modeling are providing key contributions to national and international policymaking for sustainable charcoal within energy, development, and climate agendas. Stylized representations, while enabling certain forms of analysis, can omit a host of intervening, and unpredictable, social factors that may shape how much charcoal is produced, who is producing it, where, and how. These representations may even at times reproduce Malthusian assumptions and crisis narratives around population growth and ecological degradation. In the next section, we consider four aspects of these social contexts, showing that each is characterized not by uniform informality, but by complex social processes and relations of power and inequality, which shape the charcoal sector and help determine its ecological and social impact.

3. Questioning informality

As charcoal moves firmly onto the African energy, development, and climate policy agendas, the ascendant sustainability-through-formalization narrative locates the path to sustainability in solving deficits of regulation, enforcement, organization, and technology through the formalization and improvement of production, trade, marketing, and consumption, from tree to stove, through regulatory and technological interventions. However, as we document in this section, a growing body of evidence is explicitly and implicitly raising questions about this narrative's assumptions and conclusions, revealing "informality" to be too blunt a designation for charcoal's diverse and dynamic social contexts on the African continent. Research is making clear the need to understand charcoal's contexts as shaped by ongoing social processes and by multifaceted relations of power and inequality. Thus, our exploration of informality in this section again demonstrates the need for research into charcoal's social contexts and relations to make

sense of its present and future, as called for by the narrative of charcoal in context.

In the following sub-sections, we examine four areas in which calls for formalization are frequently made – land, labor, technology, and political authority – and show that these are characterized not by a clear deficit of formalization that requires filling, but by dynamic social change and contestation, since "both the social-economic relations of charcoal and the chains of causality to forest degradation are complex and embedded within local state- society relations, forest property regimes and systems of access, in distinctive ways" [109]. For each of the four, we argue that the African charcoal sector may best be understood as characterized by complex and hybrid arrangements incorporating both formal and informal, public and private, legal and illegal [110], and that formalization does not necessarily lead to reduction of ecological and social harm, but may be ineffective or even counterproductive. Technocratic interventions may thus run up against ongoing processes, forces, and interests that do not align with its objectives and render implementation difficult or impossible. We conclude that, instead of relying on the prevalent association of informality with unsustainability, research and policy should attend to how existing social processes and uneven relations of power shape charcoal's social, economic, and ecological impact, as is illustrated by a consideration of these four arenas. To begin, we look briefly at charcoal's past in the continent, an area in need of considerable additional research so as to better understand the origins of charcoal's present ubiquity and its future possibilities [23,24,33].

3.1. Charcoal in history

The idea that Africa is on a lower rung of an "energy ladder" associated with a "least developed" status awaiting an energy transition can give rise to the image of charcoal being an outdated remnant of "traditional" energy systems. While charcoal has indeed been produced and used throughout the continent for centuries – for instance for iron smelting – its ubiquitous urban use today is a result of specific recent historical processes, policies, and political decisions. More attention is needed to Africa's diverse energy histories, to "how urban environments and energy systems have co-evolved" [23] in ways shaped by colonial and postcolonial governance, national and international political economies, rural-urban relations, and development and conservation paradigms, to make sense of the structures underlying its current prevalence.

Charcoal became part of urban energy regimes at different moments in different locations. In some African cities, charcoal use became widespread within colonial urbanism, an urbanism characterized by large, sometimes recently migrated populations whose access to cooking fuel was determined by "racialized colonial urban planning and its sparse energy infrastructures" [28]. In colonial Tanzania, for instance, production of charcoal around Dar es Salaam became a "tool of underdevelopment" as forests provided a "subsidy in nature" [111], a cheap source of urban energy that "allowed the state to then avoid investing in the energy infrastructures that would be necessary to replace its use"; the result was that "allowing peri-urban charcoal production meant the state could overlook subsidizing energy provisioning" [28]. It also was a way of providing livelihoods to peri-urban communities of rural-urban migrants who had been expelled from the urban center of Dar es Salaam by the colonial state [112]. In late colonial Kampala, Uganda, charcoal use for cooking was widespread among the expanding African population living in informal settlements throughout the city. Charcoal was produced in nearby counties and then transported by truck to Kampala, where it was sold in a sprawling, decentralized network of dealers, retailers, and hawkers, much as it still is today [113].

Elsewhere, charcoal did not become predominant in urban areas until after the end of colonial rule. In Zambia, for instance, charcoal use for household cooking, which had first arrived with Angolan workers in the 1940s in the Copperbelt, reached Lusaka in the 1960s, and spread to other urban areas by the 1980s, especially as structural adjustment

policies removed state support to rural and urban areas [71]. In the Democratic Republic of Congo, electricity was widespread for urban cooking in the immediate post-independence period, but charcoal became dominant in the 1990s with the undermining of infrastructure, incomes, and state support to both urban and rural populations by structural adjustment and state crisis [114]. In Tanzania and elsewhere, production and use also expanded under 1980s structural adjustment, as people had to find new ways to meet their energy or income needs [32], while in Ethiopia, urban charcoal use has accelerated significantly only in the last twenty years [84], as it has in Kano, Nigeria [33]. These diverse histories, taking into account factors such as different experiences under settler and non-settler colonialism, different models of colonial urbanism, and different national and regional programs for forestry, electrification, and infrastructure, require significant research.

The lack of consistent state regulation often typical of the sector today is partly a result of the specific materiality of charcoal production and trade – its low entry requirements and the widespread rural and peri-urban access to trees, transport, and markets, which make it amenable to decentralized social contexts in which people move in or out of the sector depending on changes in demand, income needs, and opportunities, able to avoid state control. But today's situation is also a result of specific historical processes. In many post-independence states, woodfuel fell solidly within forest policy. In Zambia, for instance, the Forest Department implemented strict programs of charcoal production, marketing, and forest regeneration [71]. In Tanzania, after the end of colonial rule, there was a vision of developing a modernized state-directed East African charcoal industry as a path to energy sovereignty and also for export [28,115]. In many cases, it was the structural adjustment programs of the 1980s and 1990s that helped undermine regulatory capacity and led to today's widespread lack of coherent formal regulation [32]. Political violence has also contributed to the current situation in some cases. In DRC, it was with the state crisis of the last twenty years that charcoal production and trade came to be defined by a hybrid form of formality and informality [114]. In Uganda, plans for formalizing charcoal production and trade came to an end with the 1971 takeover by Idi Amin [37], with subsequent governments focused on hydropower and, now, oil. In South Sudan, the charcoal sector is shaped by war, displacement, the erosion of customary rights to forests, and militarized natural resource extraction [100]. In short, the often deplored absence of formal state regulation is not somehow inherent to the African charcoal sector but is a contingent and, sometimes, recent historical product of different political processes and choices.

This brief historical glance signals that casting charcoal use in Africa as a case of the continent being on a lower rung of a universal energy ladder up which it is destined to climb is misleading and meaningless, often based upon a false energy "history by analogy" [116] that frames Africa as inhabiting the past of other world regions or that represents charcoal as a vestige of "traditional" African society. Instead, charcoal use has been and continues to be part of specific modern energy histories with political, social, cultural, and environmental dimensions [117–121], and the diversity of its production and trade should be seen as deriving from those divergent histories, as well as from its specific material qualities of being easily produced, traded, and consumed. This also means that interventions aiming to improve the sustainability of charcoal will necessarily become integrated into these existing processes, and that even the most technical regulatory or technological interventions will be layered upon long histories inscribed in rural and urban landscapes [117,122].

3.2. Land

When the FAO declares that "providing local people with greater [land] tenure security can increase their willingness and ability to invest in sustainable approaches" to charcoal production [2], it reflects a widespread policy assumption that rural communities are unsustainably cutting trees from land under informal tenure, often in a "tragedy of the

commons" scenario that can conform to stereotypes of rural Africans as the agents of harm of their own landscapes [123]. These policies for sustainable charcoal through land tenure formalization are situated within a broader context of such tenure formalization efforts that have been implemented in Africa since the colonial period with divergent intended benefits, approaches to forest and woodland ecologies, and outcomes [124–127]. Within this context, the ascendent sustainability-through-formalization charcoal narrative proposes to create woodlots, expand plantations, and formalize tenure so as to incentivize rural inhabitants to plant trees for charcoal or leave trees uncut. Prevalent neoliberal logics often equate formalization with privatization and individualization or with prices on open-access resources.

However, the research we explore in this sub-section has shown that, in many cases, it is not the supposedly short-sighted behavior of rural inhabitants amidst a lack of formal land tenure that determines where and how trees are cut and that is driving unsustainable extraction. Rather, we need to look to existing dynamic social processes, other drivers of land-use change, and the complex arrangements of power, authority, and often, violence, around land and trees as determining where, how, and by whom charcoal is produced and with what impact [128]. While the sustainability-through-formalization narrative may assume a lack of land tenure arrangements in rural African settings, the opposite is often the case, as parcels of woodland or forest can be subject to extensive and diverse existing management practices and claims. These may be overlapping or competing, based upon a complex array of national or local institutions, customary tenure systems, market-based property rights, historical narratives, or demands for justice [129–132]. The assumption of informality and lack of regulation also hides the significant diversity of lands from which charcoal is produced, including forest reserves, private forests, customary woodlands, on-farm trees, community or individual woodlots, or extensive plantations, each under different arrangements among different actors and institutions [84]. Indeed, in some locations over 80% of wood used for charcoal already comes from privately owned land and farms [133,134]. Or, charcoal may be produced alongside agricultural clearances for rotational subsistence farming or for large commercial operations. Large producers can negotiate with communities in order to secure access to trees for a single cutting or sometimes for years [135], negotiations that can be sites of exploitation and violence [19,136]. In short, complex – and sometimes hard-to-discern – structures of power and authority provide the context in which a variety of actors decide what land and trees are used for charcoal. Research is thus needed into how these many existing access, control, and ownership arrangements shape charcoal production's relation to other land uses and thus help determine its ecological impact and sustainability [67,69,84,101].

The picture of a static informality of land tenure is challenged by the recognition of dynamic processes and transformations in land and forest access, use, and ownership that are shaping how, where, and by whom charcoal is produced, and that charcoal reshapes in turn, as forests become "significant zones of contention" in the "emerging rural environmental politics of the twenty-first century" [103]. For instance, the insecurity over land that has been identified as enabling unsustainable production may be the result not of informal tenure but of large commercial charcoal dealers making underhanded deals or grabbing land or trees for extraction [19], within a wider setting of land grabbing for farming, conservation, or infrastructure, often with state involvement [137]. People may cut down trees for charcoal in an effort to extract some value from land before it is grabbed, or to try to prevent new conservation areas from being established. These signal neglected but potentially important land policy pathways to energy sustainability – for instance, through protection from land-grabs or by including land and environmental issues in post-conflict peacebuilding, since the insecurity over land characteristic of post-conflict areas can be targeted by charcoal producers taking advantage of destabilized social order, regrowth in abandoned areas, and militarized infrastructure [100].

Charcoal production may also be usefully framed within ongoing transformations of customary or collective land tenure towards market arrangements [138] and the often unequal impact of these transformations along lines of livelihood, class, gender and generation. Charcoal production can be driven by, and contribute to, these wider land commodification and individualization dynamics [139]. Those with access to trees may capitalize on new opportunities for charcoal income, and thus seek to secure and clear-cut collective woodlands subsequently claimed for agriculture, or to plant trees to establish exclusive land claims [140]. Specific "regimes of accumulation" can result [46], with inequitable returns from emerging market structures [135]. Marginal landholders and forest-based communities tend to suffer significantly from the loss of communal land. Indeed, reforms intended to bolster the security of land tenure via formalization can paradoxically result in considerable insecurity of tenure instead, as formalization processes may precipitate competitive land grabs "from below" [84,141,142]. Conversely, the collective defense of communal land and forests against charcoal extraction can serve as an obstacle to land individualization and commoditization and become part of wider environmental or land struggles. There are important gendered dimensions to these transformations as well, given the gendered nature of land tenure and usage entitlements [143], leading to unequal distributions of social and environmental harms. Instead of an often assumed equation of land formalization with sustainability, the possibilities for informal, customary, and collective forms of land tenure to provide a basis for the just and sustainable production of charcoal can be a rich vein for research.

3.3. Labor

The dominant image of labor in the charcoal sector is, again, one of informality. For instance, in the UNDP's words, charcoal in Uganda is produced by "unorganized groups or individuals", often the "poorest of the poor", unsustainably exploiting their environment [30], but earning so little that they can end up caught in "charcoal traps" of ecological degradation and poverty [144]. Most proceeds are assumed to accumulate among equally informal middlemen and traders, the "large spectrum of people looking to take advantage of the relatively high price difference between the money paid to the producers and the final price paid by consumers" [30]. Thus, formalization of production labor, whether through charcoal producers' associations, local collectives, wages, taxation, or licensing and other production regulations, has been proposed and instituted as a path to ecological sustainability and sustainable development [145–147]. So, too, has the formalization of trade and marketing, often involving complex plans for organized and centrally regulated collection, warehousing, transport, and sales. Increased capital investment may be presented as part of the solution, reflecting "a broader shift within the international development community towards supporting private-sector-led development" [90].

However, charcoal labor, whether in production or trade, like land, is characterized not by uniform informality, but by socio-economic differentiation and diverse hybrid forms. People produce charcoal for many reasons: survival, subsistence, school or medical fees, capital for further investment, or significant profits [67,87,135,148,149]. Production can be performed by a range of labor arrangements, from large work crews contracted and supplied by commercial dealers, to individual migrant laborers, local full or part-time casual workers, peasant farmers individually or in groups, displaced persons, or forced labor, sometimes women and sometimes men, sometimes organized around ethnicity, class, age, or nationality [74,87,90,135,150]. Dominant labor arrangements can quickly shift in response to social or political pressure. In northern Uganda, for instance, violent opposition to outside work crews being brought in led charcoal dealers to hire local youth instead [151]. One result of this diversity is divergent allocations of economic benefits: while low proceeds to producers is the norm, with less than 10% accruing to producers in some cases, in other cases, producers have been documented as earning over 50% of the final price

[84,90,135,148,149,152,153]. There are significant differences in terms of the distribution of benefits and harms within rural communities as well. In his classic study in Senegal, Ribot reports that most "villagers experienced the charcoal trade as an uncompensated loss of the forests which supplement subsistence needs," while local elites and male heads of household benefitted [136].

This variation in charcoal production labor and its proceeds is shaped by many factors, among them existing structures of power and inequality. Those with access to capital or authority, especially along lines of class, gender, or political affiliation, are often seen to disproportionately benefit, while those with less power suffer the economic and environmental harm [90,135,154,155]. Charcoal can re-shape these social relations in turn, as new sources of income and modes of labor are accessed and threaten existing balances of power. Different labor arrangements can have divergent ecological consequences and implications for sustainability: workers have different degrees of mobility, use different tools and techniques, and have different incentives and interests, leading to different production, cutting and management practices and relations with the environment. For instance, well-capitalized work crews may not hesitate to clear-cut or uproot trees to burn, while small-scale producers in their own homes may take care with cutting, carbonization, and post-harvesting forest management [19]. Ignoring this diversity can lead to sustainability policies that target small-scale producers for restrictive regulation while giving a free hand to large, and often politically connected, producers despite their responsibility for social and ecological harm.

To make sense of this diversity and its social and ecological consequences, charcoal production labor, instead of being categorically labeled informal, should be located within local, national, and international political economies and their underlying relations of power and inequality. Recent studies are going beyond the focus on distribution of proceeds along the value chain [90] to show how charcoal's connection to ecological sustainability and development depends on its interaction with broader economic contexts, in particular livelihood activities such as agriculture, grazing, or wage labor [69,84]. Where production labor is indeed informal, this, too, should be contextualized. The growth of informal labor is not an inevitable facet of African rural settings and population growth, but has been linked to economic restructuring driven by recession and globalization, and may be a product of state and donor policy [156]. Emerging pools of informal rural labor, encouraged by the expansion of global value chains, may thus drive the turn to charcoal production more than population growth or land scarcity.

Beyond production, the charcoal trade is also characterized by diverse degrees of formality and structures of power and inequality. Systems range from small producers themselves using bicycles to transport a sack or two, to small-scale local middlemen, to dealers from urban areas, large cartels with state connections, or the military and other armed groups transporting thousands of tons hundreds of kilometers [106,157]. All have different arrangements with forest departments, police, revenue collectors, border agents, and market owners. These commercial structures and the associated labor arrangements can be highly regularized, with significant vertical integration and enforcement power, even if outside of formal state regulation. Charcoal can thus move through zones of relative formality and informality, legality and illegality, at different points of its progress from tree to stove, as transporters and dealers negotiate among public and private authorities [18]. The structure of these trade relations and commodity chains have social and ecological consequences in terms of where charcoal is cut, how, by whom, and with what impact. For instance, shorter chains to smaller markets have been documented to be more equal and less environmentally harmful than longer chains to larger markets, which involve larger dealers with less accountability [158]. Studies also suggest there may be more involvement of women around smaller urban centers than around major cities [90]. National policies, from the withdrawal of agricultural subsidies to forced settlement and dispossession of pastoralists, can push people into unsustainable and low-paying charcoal production or allow large producers to exploit vulnerable environments [159].

Charcoal's entwinement with dynamic labor processes, with attendant environmental consequences, is not limited to rural areas. The urban use of charcoal has primarily been treated as a matter of consumption, with attention to the inequitable gendered health impact of indoor pollution upon women doing the cooking [160]. However, cooking with charcoal and acquiring it from markets can also be seen as a form of labor that helps to establish the gendered division of labor within urban households, enabling certain forms of male labor as well [161]. How broader changes to urban labor are affecting the future of charcoal use and energy more broadly and how changes to charcoal supply may affect urban labor represent an underexplored research terrain, but can draw upon a significant existing literature on gendered household labor in Africa within the context of national and international political economies and a growing body of urban energy histories [162,163].

In short, the sustainability of charcoal is not rendered impossible by supposedly ubiquitous informal labor, but it is shaped rather by charcoal labor's role within diversely structured charcoal value chains as well as within broader political economies. People decide, or are driven, to produce, deal, or use charcoal, sometimes despite knowing its environmental harm, as a result of complex political, economic, and ecological forces in which they are enmeshed and over which they often have little control. Other actors, meanwhile, are able to impose charcoal's harms on the more vulnerable without accountability. Still others are able to find diverse ways to produce charcoal sustainably using different forms of labor, despite the obstacles to doing so. Categorically attributing unsustainable charcoal production to informal labor obscures these diverse local, national and international structures of power and inequality.

3.4. Technology

The sustainability-through-formalization narrative tends to place significant blame on "simple [production] technologies with low efficiencies" [2], inadequate knowledge among informal and untrained workers, poor forest management practices, and inefficient cooking with "unimproved" stoves for today's unsustainably high levels of charcoal consumption and production. Thus, according to today's ascendent narrative, drawing on several decades of policy interventions, sustainability demands the formalization of technology through improved kilns, better forest management, charcoal standards, and improved stoves [29]. However, we would emphasize the often-made point that technology's impact derives both from the characteristics of the technology itself as well as from the social contexts and underlying relations of power within which those technologies are deployed [14,17,164]. This attention to how and by whom technologies are used is a necessary corrective to the sometimes uncritical promotion of technological improvements as a self-evident fix to charcoal's apparent unsustainability.

The relation between improved technologies and ecological sustainability is highly mediated, both by social context and by the broader production setting, including forest management. Shifting from machetes and bicycles to chain saws and lorries can lead to industrial-scale forest destruction; but such improved tools can also be an essential part of improving the productivity of short rotational forestry for charcoal production. Where there are limits on the total amount of charcoal that can be sold, whether due to regulations, market structure, or the nature of the incentives for producers, more efficient production can reduce total extraction of wood. One study found that training charcoal producers on drying wood well, arranging it to allow air flow, and monitoring kilns improved charcoal yield significantly in DRC [165]. However, in other cases, more efficient kilns and increased yield may not reduce tree extraction but rather encourage additional production in a "rebound effect" that takes advantage of latent demand, especially among the large producers able to afford improved kilns, deploy

additional labor, and access distant markets – a charcoal Jevons paradox [20,82,166]. The capital and organizational demands of technology acquisition and maintenance can thus, in some cases, benefit well-capitalized producers and squeeze out smaller producers, expanding unsustainable large-scale commercial production. In short, it is not only the level of technology but the economic and social structures within which production, trade, and use are taking place that determine the relation between technology and sustainability. Research and interventions need to address forest management, production kilns, and stoves together within a systemic approach that is situated within broader social structures.

The issue of kiln efficiency illuminates this need for social contextualization. Kiln efficiency is often taken as the key technical determinant of sustainable charcoal production, and figures are invoked of the inefficiency of "traditional" earthmound kilns – around 10–15% is a common measure [4] – as testimony to the massive waste associated with the present charcoal industry and as clear evidence for its unsustainability. Today's sustainable charcoal narrative thus envisions earthmound kilns being improved through design innovations or being replaced entirely by brick or metal kilns – again, drawing on several decades of research and policy experiments around such designs. Clearly, efficiency depends in part upon kiln design, but the exclusive focus on technical determinants of kiln efficiency ignores its social determinants. The efficiency of production is affected significantly by many aspects: who is using the kiln, how carefully and expertly they are using it, what their motivations and incentives are for production, whether production labor is part-time or full-time, where the wood comes from, what species are used, how it is dried before carbonization, and even whether production is legal or illegal [167]. Thus, even basic technologies, and small tweaks to those technologies, in the hands of accountable, small-scale producers can be the basis for sustainable production [168], just as advanced technology in the hands of unaccountable producers can worsen environmental impacts. Similarly, the ecological consequences of specific harvesting and post-harvesting practices may depend as much on technical expertise as on producers' relation to the land and trees. On the consumption end, attention is needed both to the technological design and to the social context in which stoves are purchased and used, as these can have an important impact on levels of charcoal consumption, wood harvested, and indoor air pollution [169]. The assumption that improved technologies and expert knowledge of carbonization efficiency, cutting techniques, woodlands management, and charcoal use represent the self-evident solution for sustainability can marginalize practices developed through long artisanal experience [164,170]. It can also ignore the locally situated knowledge of communities' long-term engagement with always partially anthropogenic forests and woodlands [103]. What technologies and knowledge are available, and what their impact is, will be shaped by social context and contestation, and a focus on technological fixes should not result in overlooking how technology is deployed, in whose interests, and to whom it is accountable.

3.5. Political authority

At the heart of the new narrative of informality and unsustainability is an assumed deficit of state regulation: "The charcoal sector, which is largely informal, generates income for more than 40 million people, but a lack of regulation means that it promotes inefficiency and governments forgo billions of dollars in revenue" [2]. The path to sustainable production is thus envisioned as addressing this regulation deficit by promoting the "coherence of charcoal policies with globally recognized principles and regimes" [2].

However, the absence of coherent, consistent formal state authority governing charcoal production and trade does not, of course, mean that the sector is devoid of regulation or control, whether by the state or by other public or private authorities or actors [153]. Instead of an assumed uniform informality defining charcoal sector governance, hybrid arrangements of formal and informal authority can predominate, bringing together customary or traditional authority structures, local government, national ministries, military, police, forest guards, community organizations, national and international NGOs, and others [118,153,171,172]. The label "informal" can obscure these many existing structures of public and private authority that effectively regulate this multi-billion-dollar industry. How, where, and by whom charcoal is produced, and with what ecological impacts, are thus often determined not by unorganized actors making decisions in the absence of authority, but rather by a multiplicity of authorities with competing claims on trees, charcoal, taxes, and transportation routes, shaped in turn by existing political processes and structures. The idea that "best practices" can be established simply through technical intervention amidst a regulatory vacuum ignores this fraught and contentious context within which any intervention inevitably becomes an active, and partisan, player. Thus, there is no guarantee that the regulations, institutions, and bureaucratic reforms called for by the formalization agenda will be smoothly and impartially implemented, as is sometimes imagined, nor that those reforms will have their intended effects if they are implemented.

States and their component parts can be deeply involved in the charcoal sector, even in the absence of coherent formal state authority, often instrumentalizing the lack of clarity and accountability to their own advantage. Rents can be extracted from various points of the value chain, a source of profit to regime allies and clients or a subsidy to low official salaries through corruption or extortion. One pattern is for complex, overlapping, and disjointed regulatory schemes to be enforced at the discretion of various officials. Production, transport, and trade can thus occur in a legal grey area, where producers and dealers end up entwined with state agents in complex and shifting arrangements of power and money, subject to unpredictable bouts of repression, even taking on aspects of organized crime in some cases [18]. In Madagascar, 80–95% of production is unlicensed [155]; while in Burkina Faso, most production takes place outside of the officially designated, donor- and state-supported sites [146]. These arrangements can vary dramatically among different commodity chains even within the same country, with different income [153,173] and gender impacts [174]. In extreme cases, charcoal can fund violence, becoming a conflict resource for armed groups [157].

In these power-laden contexts, formalization may bring benefits to those harmed by charcoal production, for instance where restrictions are placed on large extractive enterprises to make them accountable, or where abuses by state officials are curbed. However, it can also lead to counterproductive consequences. State projects to control or ban charcoal production can represent the extension of sometimes violent state force into forests and rural communities in the name of preventing deforestation or smuggling, often targeting for repression those communities deemed to be recalcitrant [20,175,176]. Formalization and criminalization can further marginalize grey-area production, driving small producers into illegality and precarity, such as in Malawi, where all production today is formally illegal, rendering an entire industry "criminals by necessity" [174] and vulnerable to the arbitrary power of police and state officials. Those with the economic or political clout needed to abide by complex regulations or avoid enforcement can benefit and squeeze out those without access to resources or power. Where the state controls the sector, local government may even seek to unsustainably maximize production to raise revenues [32]. Formalization can thus give more power to those already advantaged [136,153], as "experiences from sub-Saharan Africa…suggest the ineffectiveness and 'anti-poor' impacts of formalization," risking "marginalizing the poorest" [84,89,172]. These can have gendered impacts: for instance, where women are the most small-scale and vulnerable producers, criminalization can impact most harmfully upon them [90].

These structures of power reach to the international level as well, as African states' dependence on charcoal – for energy and income – is in part a product of the energy inequality associated with international

structural economic inequality [119]. Africa's position as an exporter of raw materials, for instance, gives rise to the apparent paradox that Nigeria, Africa's largest oil exporter, is also its largest producer of charcoal for domestic consumption [33]. Dams are built to produce electricity for export or for domestic elite use, while charcoal for the urban poor is produced from cleared land [121]. Charcoal reduces pressure on the state for a widespread consumer-oriented energy transition – proclamations of mass electrification notwithstanding – thus allowing electrification and fossil fuel development to be focused on use by industry and urban elites [37].

One increasingly prominent route through which international-level formalization is taking place is charcoal's incorporation into REDD+ initiatives and flows of finance, as global authority is exerted over African landscapes and people [177], often in collaboration with states. Caution is warranted here as well, since research has shown the social and environmental harms that REDD+ and carbon forestry initiatives can cause, as local people may pay a steep price for global emissions mitigation through loss of land, forest access, livelihoods, or autonomy [122,177–181]. This takes on added relevance given the call for REDD+ initiatives in Africa to focus further on degradation instead of deforestation [61], which could lead to even more invasive systems of surveillance and discipline required to measure and curb degradation [182,183]. And so it is little surprise that, as green charcoal initiatives proliferate, they have run up against social, political, or ecological barriers [120]. These include community resistance against the mal-distributive impacts of greening projects in Tanzania [184], the rejection of "idiots' charcoal" made through green technologies in DRC [118], or outright "failure" in Uganda [185].

In short, political and regulatory formalization does not guarantee greater sustainability or equity. Rather, depending on the social and political context, the imposition of regulations can represent an intensification of unaccountable power over rural communities or the extension of ecologically damaging and impoverishing production. What may matter most is not whether production and trade are formal or informal, but rather the nature of the structures of power and inequality underlying the sector and the accountability – formal or informal – of those organizing and regulating production and trade [87,89,154,155]. Existing studies of the politics of charcoal tend to focus on the distribution of power along the value chain as it determines the distribution of access to and benefits from the sector [19,135,154,155]. Needed also are mappings of the broader political structures and interests, within local and global contexts, underpinning the charcoal status quo in different locations, which determine its present and future ecological and social impact [90,101].

4. Conclusion: just energy transformations

The picture of charcoal in Africa that is emerging – as much from today's charcoal research as from multiple longstanding disciplinary traditions – challenges both the still-dominant Malthusian crisis narrative as well as the ascendent narrative of sustainability through formalization. Discrete constellations of charcoal governance are arising from everyday social and political processes, as well as from deliberate decision-making that spans local to global scales, all entwined with dynamic ecological processes. These can best be approached, we argue, through the narrative of charcoal in context. The transformation of the charcoal sector towards sustainability is thus unlikely to be the simple result of regulatory formalization and technological fixes. Rather, it will depend upon transforming the structures that underpin the charcoal sector at the local, national, and international levels and addressing the diverse interests served by today's energy status quo, recognizing that "energy interventions are the outcome of complex and diverse processes of resistance, negotiation and contestation, often with unintended consequences for both nature and society" [33]. Taking this broad social and political life of charcoal into account is necessary for research as much as for building alliances towards just and equitable energy

transformations. Indeed, longstanding tendencies to neglect such contextual factors may help explain why many efforts at sustainable charcoal have ended in failure.

This picture is sobering, since it cautions against easy solutions to charcoal's significant harms. Indeed, the charcoal-in-context narrative itself is a recognition of charcoal's diversity and complexity, rather than a simple diagnosis and solution. But this picture is also potentially empowering because it can provide a reorientation for analysis to inform not only policymaking, but also, given that the policymakers themselves are sometimes part of the problem, civil society and activist initiatives working towards environmental, climate, and energy justice. It also points towards distinct values that can underpin charcoal research. While clear-eyed assessments of the dramatic challenges arising from social and ecological systems are crucial, there is also a need for research to avoid alarmist overgeneralizations and oversimplifications that may be amplified by media and feed into crisis-driven policymaking. This reorientation can take shape through more collaborative, interdisciplinary efforts to expand geographic coverage and account for diverse social, cultural, and political contexts, and more critical interrogation of both dominant narratives and data sources [101]. It also requires research that makes an effort to work with policy makers to understand their challenges and limitations as well as with the communities that face the very real impacts of charcoal production upon their lives and livelihoods. Finally, it requires recognizing discrepancies between the visions expressed in charcoal policies and the realities on the ground, addressing charcoal as distinct from other biomass sources, and acknowledging the key distinction between household energy requirements for cooking and heating versus for lighting and appliances.

We contend further that there is a case to be made for expanding the dominant policy focus on sustainability, given the many methodological, empirical, and ethical questions it raises, to include an equal focus on environmental and energy justice [186,187]. As we move away from crisis narratives of imminent charcoal-driven ecological collapse, whatever conclusions are reached concerning the sustainability of charcoal production at present and in the future, there is no doubt that production is causing immense ecological and social harm in many locations. Attention is being called to this harm by rural communities chasing away charcoal burners and corrupt officials, customary leaders putting trees off-limits, and environmental justice movements and NGOs leading protests and raising demands in national and international forums [136,171,184]. Expanded research into the contexts of charcoal production and trade can help clarify these experiences of charcoal's harms and foster a re-orientation of charcoal policy away from a sometimes technical and globally driven idea of sustainability and towards a more substantive and locally driven vision of environmental and energy justice, one in which policy and technological interventions are comprehended within their social and political contexts.

Transformations of energy regimes, or parts of those regimes, are messy, uneven, and often very partial [188]; they are driven by sometimes unexpected social alliances – not by donors or states alone nor solely by communities' efforts or demands – in diverse efforts among policymakers, activists, and communities. The future of charcoal will necessarily grow from the political choices, mobilizations, contestations, and alliances that infuse the political ecology of energy on the African continent, in all their diversity and complexity, recognizing tensions and trade-offs. We believe that the growing body of innovative research on charcoal in its many contexts can provide a critical contribution to these ongoing projects of just energy transformation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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